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Sky at Night

#164 JANUARY 2019

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EXCLUSIVE INTERVIEW

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Sky at Night MAGAZINE REVIEWED IN ISSUE 112 SEPTEMBER 2014 ★★★★★

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This month's contributors include...

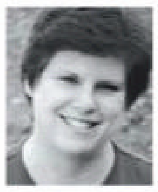
Terena Bell
Science journalist

Terena has been investigating the extent to which NASA is now relying on artificial intelligence to run its missions. *Page 44*

Will Gater
Astronomy author

Space agencies around the globe have some major missions planned for 2019 – Will gives you the rundown. *Page 32*

Phyllis Lang
Astro software developer



Phyllis has long had a fascination with green stars, and this issue she shares her tips on spotting them with you. *Page 38*

Gary Palmer
Astrophotographer

Few people know CMOS cameras like Gary, who has some expert advice to share on using them for deep-sky imaging. *Page 73*

Welcome

See the Moon go red and the stars go green

The New Year couldn't start much better for amateur astronomers, with an eagerly anticipated total lunar eclipse occurring on the morning of 21 January. Watching the full Moon turn from bright silver to deep grey to rich red is a captivating spectacle, and it will be fascinating to assess and record the shade of the Moon during totality since every eclipse is different. The entire event will be visible from the whole of the UK; make sure you don't miss it by noting the timings on page 52, and turn to page 64 for our expert guide on how to get great photos of the event.

There's a chance to experience colour of another kind with our feature on page 38, where you'll find a guide to the most green-tinged stars in the northern hemisphere. As our author is quick to point out, the stars in the guide merely give the impression of being green – many are doubles where the colour contrast lends one star in the pair a verdant appearance. Nevertheless, it's interesting to see if you personally can detect an emerald hue, and whether other observers you know can as well. Let us know too!

While no star's colour is truly, visibly green, they do emit green light as part of a broad spectrum. In this issue we take a look at DayStar's new solar filter, which isolates this very wavelength and gives views of the Sun that are visibly green at the eyepiece. See what fascinating, new solar features the Magnesium I b2 filter reveals in the First Light review on page 98.

Enjoy the issue, and Happy New Year!

Chris Bramley Editor

PS Our next issue goes on sale on 24 January.

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Editorial enquiries
0117 314 7411
9.30am to 5.30pm, Mon to Fri

Advertising enquiries
0117 300 8276

Print subscription enquiries
bbcskyatnight@buysubscriptions.com

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Editorial enquiries
contactus@skyatnightmagazine.com

Subscription enquiries
UK enquiries: FREEPOST IMMEDIATE MEDIA
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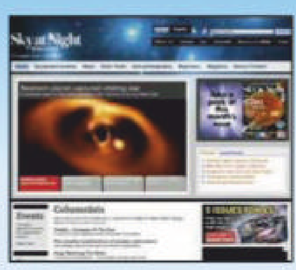
Editorial enquiries
BBC Sky at Night Magazine, Immediate Media Co Bristol Ltd, Tower House, Fairfax Street, Bristol, BS1 3BN

Sky at Night Lots of ways to enjoy the night sky...

TELEVISION
Find out what *The Sky at Night* team will be exploring in this month's episode on page 17



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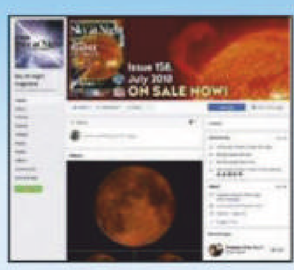

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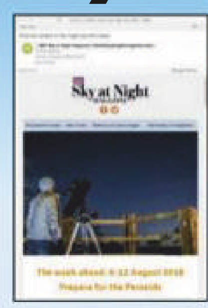

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Get started with The Guide on page 78 and our online glossary at www.skyatnightmagazine.com/dictionary

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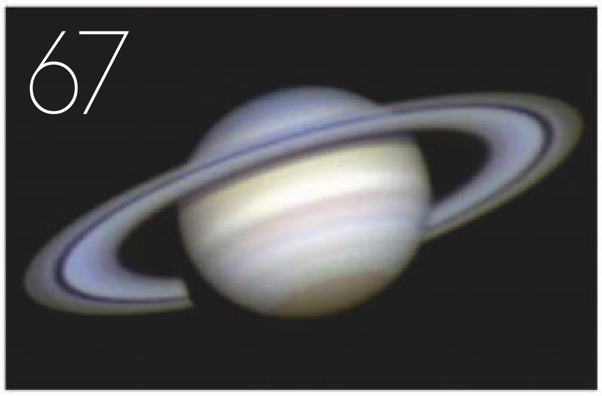

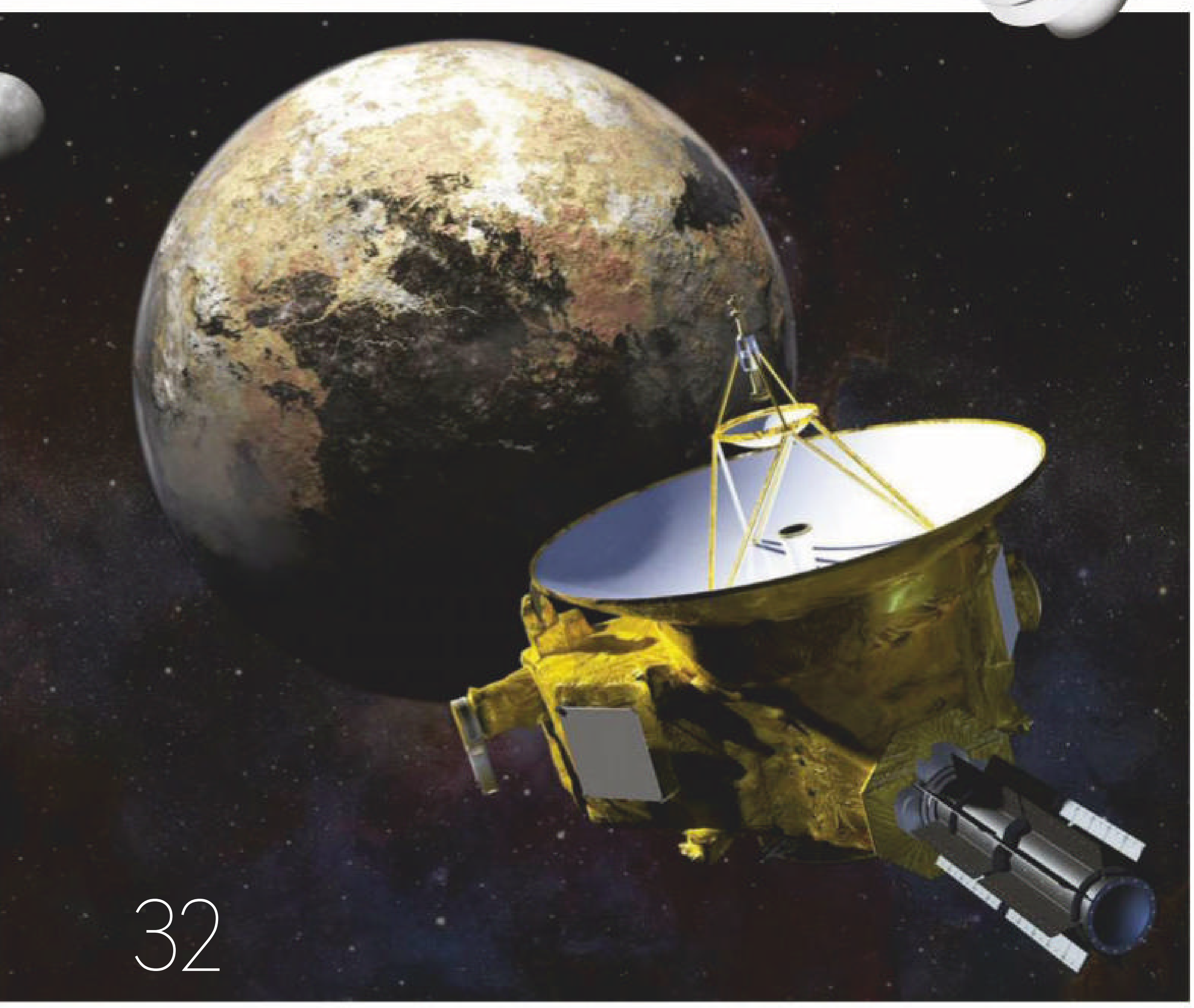

Regulars

JANUARY'S BONUS CONTENT

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Visit **www.skyatnightmagazine.com/bonuscontent**, select January's Bonus Content from the list and enter the authorisation code **EZEHWAX** when prompted

THERE'S MORE ONLINE

January highlights

How Kepler changed the Universe

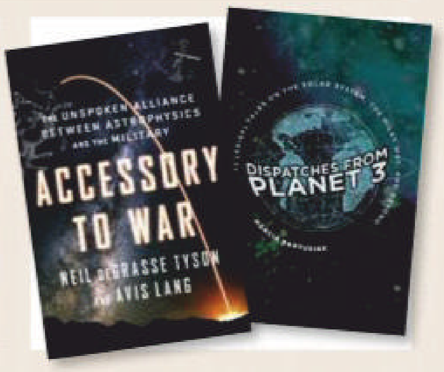
NASA's Kepler space telescope has completely revolutionised our view of the cosmos. The orbiting observatory spent almost a decade looking for planets around stars beyond the Solar System, but has now run out of fuel. Watch our interview with NASA Kepler scientist Geert Barentsen, who reveals some of the amazing discoveries made by the mission.

A guide to the constellations

Download PDF pages from *Seeing Stars*, a new book for young astronomers on the mythology of the night sky.

Watch *The Sky at Night*: BepiColombo

Maggie and Chris explore the science behind a new European mission to study the planet Mercury up close.

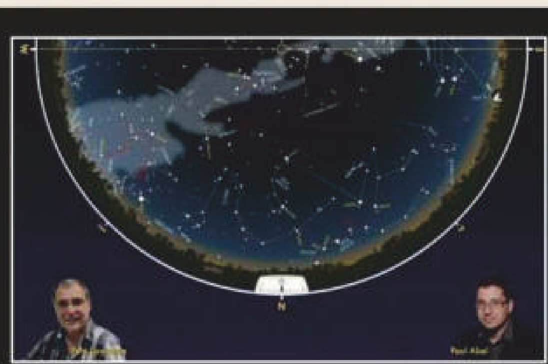


Download and listen: astro audiobooks

Hear the opening chapters of new audio titles from Neil deGrasse Tyson and Marcia Bartusiak.

And much more...

- ▷ Hotshots gallery
- ▷ Eye on the Sky
- ▷ Extra EQMOD files
- ▷ Binocular Tour
- ▷ Equipment review guide
- ▷ Desktop wallpaper
- ▷ Observing forms
- ▷ Deep-Sky Tour chart



EVERY MONTH

Virtual Planetarium

With Paul Abel and Pete Lawrence

Discover January's night-sky highlights with Paul and Pete

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EDITORIAL
Editor Chris Bramley
Managing Art Editor Steve Marsh
Art Editor Seth Singh
Production Editor Dave Golder
News Editor Elizabeth Pearson
Staff Writer Iain Todd
Reviews Editor Paul Money

CONTRIBUTORS
Paul Abel, Terena Bell, Shaoni Bhattacharya, Sean Blair, Lewis Dartnell, Glenn Dawes, Ian Evenden, Will Gater, Alastair Gunn, Tim Jardine, Phyllis Lang, Pete Lawrence, Chris Lintott, Neil McKim, Gary Palmer, Jonathan Powell, Katrin Raynor Evans, Steve Richards, Steve Sayers, Paul Sutherland, Stephen Tonkin, Jenny Winder

ADVERTISING SALES
Advertising Managers
Neil Lloyd (0117 300 8276), Tony Robinson (0117 314 8811)
Inserts Laurence Robertson (00 353 87 690 2208)

PRODUCTION
Production Director Sarah Powell
Production Coordinator Derrick Andrews
Ad Services Manager Paul Thornton
Ad Coordinator Georgia Tolley
Ad Designers Cee Pike, Andrew Hobson
Reprographics Tony Hunt, Chris Sutch

LICENSING
Director of Licensing and Syndication Tim Hudson
International Partners' Manager Anna Genevier

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Head of Circulation Rob Brock
Head of Marketing Jacky Perales Morris
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PUBLISHING
Publisher Jemima Dixon
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MANAGEMENT
CEO Tom Bureau

BBC STUDIOS, UK PUBLISHING
Director of Editorial Governance Nicholas Brett
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UK Publishing Coordinator Eva Abramik
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YOUR BONUS CONTENT

A gallery of these and more stunning space images

Remains to be seen

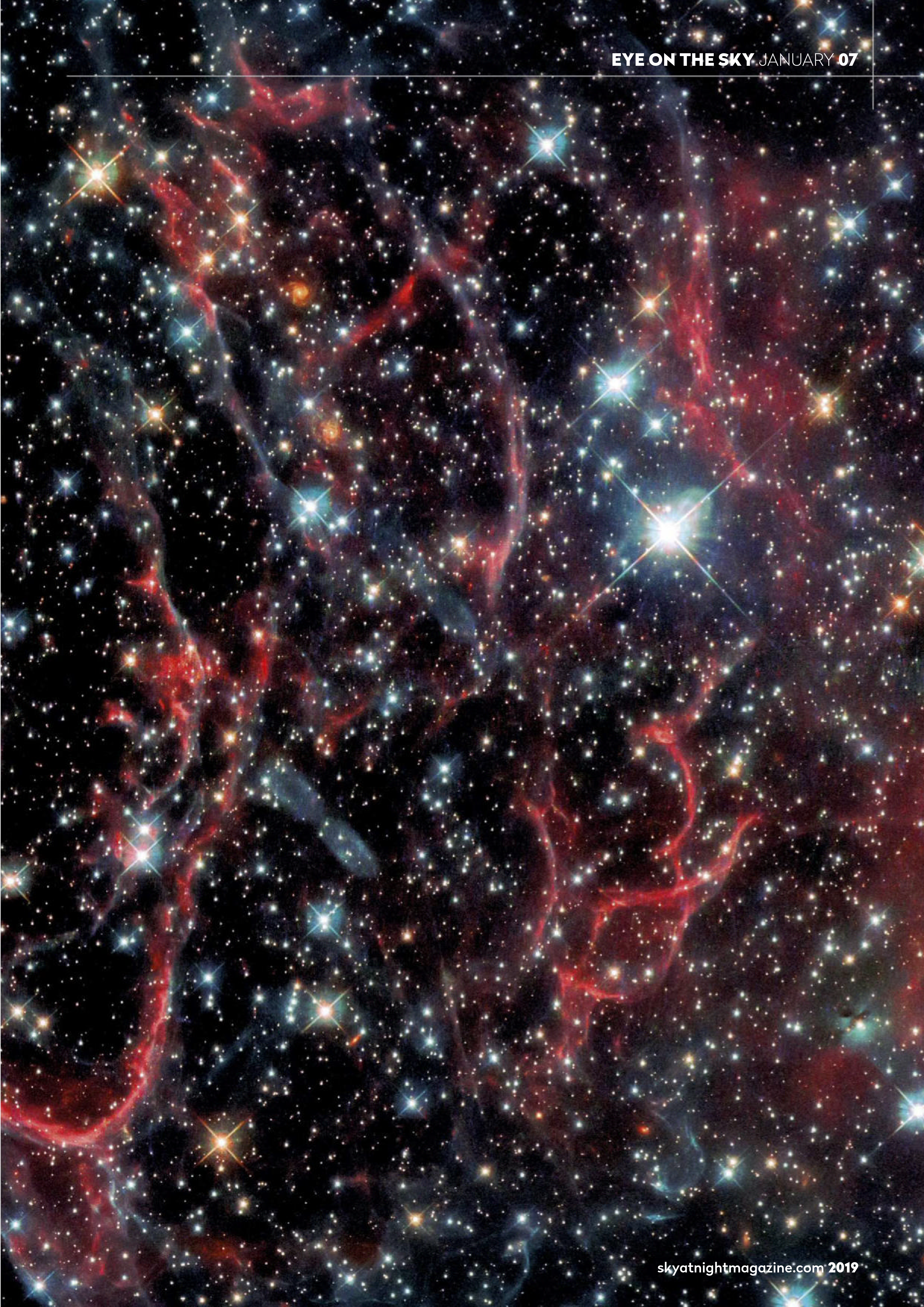
Spotting an exploding star is a challenge even for modern telescopes, but such catastrophic events do leave traces behind

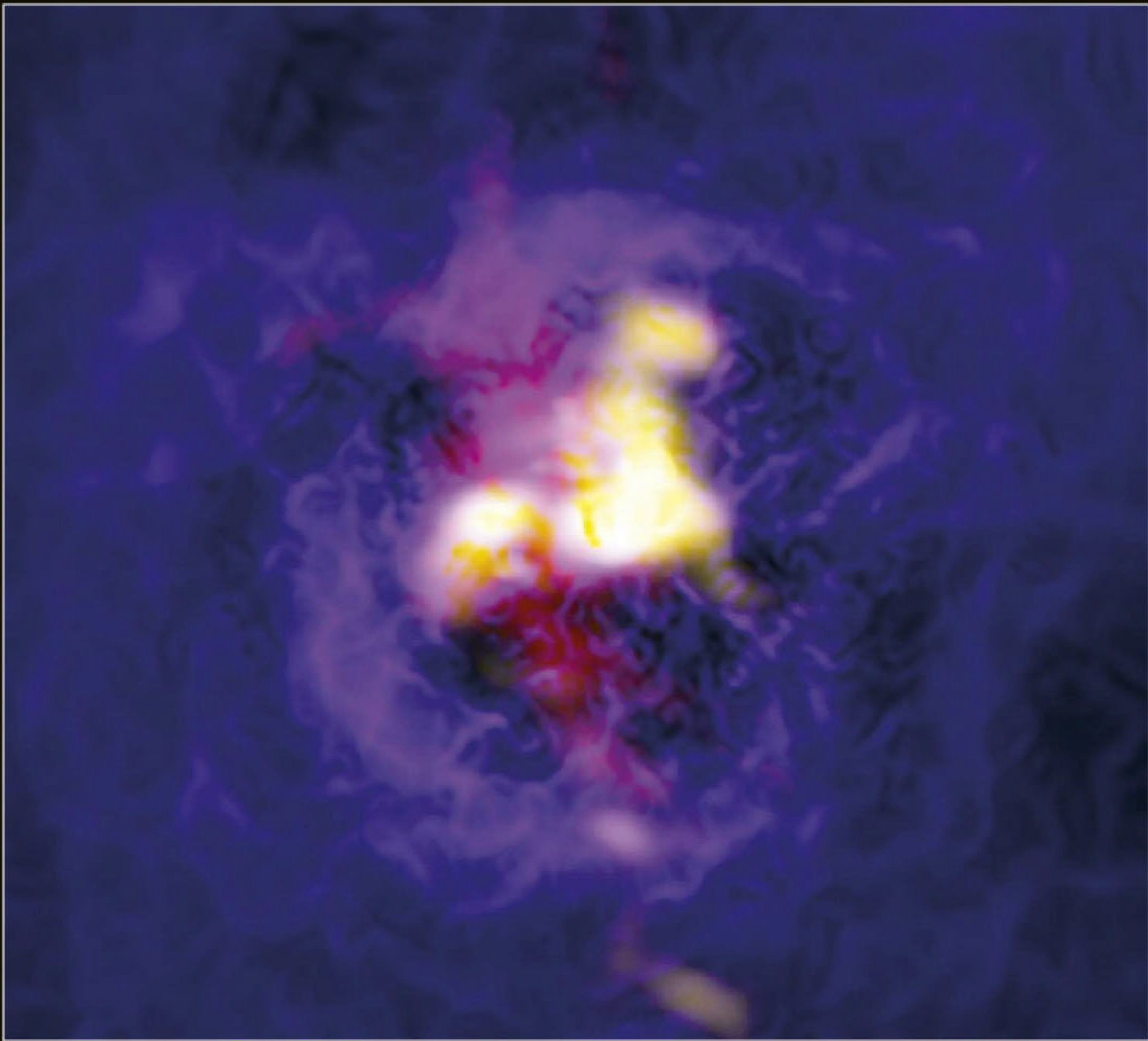
HUBBLE SPACE TELESCOPE, 26 NOVEMBER 2018

Massive stars rarely go gentle into that good night: the biggest stellar objects end their lives in gigantic, violent explosions known as supernovae. Astronomical records from millennia ago suggest they have been seen before in our skies – appearing as temporary, yet very bright objects – but none has been recorded since the invention of powerful telescopes. It is, after all, difficult to predict when one will occur.

Instead, astronomers observe supernova remnants: the smoking guns left after a massive star has exploded. The tangled, red filaments seen here are a supernova remnant named SNR 0454-67.2 located in the Large Magellanic Cloud, which is a dwarf galaxy close to our own Milky Way. Once a massive ball of nuclear fusion, these red twists of cosmic dust and gas are now all that remains.

ESA/HUBBLE, NASA





▲ A vicious cycle

VERY LARGE TELESCOPE, CHANDRA X-RAY OBSERVATORY, ATACAMA LARGE MILLIMETER/SUBMILLIMETER ARRAY, 6 NOVEMBER 2018

There's a misconception that black holes are simply huge cosmic suckers, when in fact these stellar behemoths can also propel material outwards. Here, cold gas (yellow) is falling towards a black hole at the centre of a galaxy in galaxy cluster Abell 2597. This process generates energy powerful enough to launch jets of plasma (red) out into the cosmos.

▶ Shock waves through the cosmos

CHANDRA X-RAY OBSERVATORY, LOFAR, SLOAN DIGITAL SKY SURVEY, 15 NOVEMBER 2018

Data from three telescopes combined to produce this image, showing collision on a grand scale. Abell 1033 is an object consisting of two galaxy clusters smashing into one another. Shock waves from the crash are colliding with jets of particles, seen here in blue, that are being ejected by a supermassive black hole at close to the speed of light. Studies suggest electrons in the jet on the left have been reenergised by the shock waves rippling through them.

ALMA (ESO/NAOJ/NRAO), TREMBLAY ET AL.; NRAO/AUI/NSF, B. SAXTON; NASA/CHANDRA; ESO/VLT/ X-RAY: NASA/CXC/LEIDEN UNIV. / F. DE GASPERIN ET AL; OPTICAL: SDSS; RADIO: LOFAR/ASTRON, NCRA/TIFR/GMRT/ SOLAR DYNAMICS OBSERVATORY, NASA./ ESO/CALLINGHAM ET AL.

Astro asps ▶

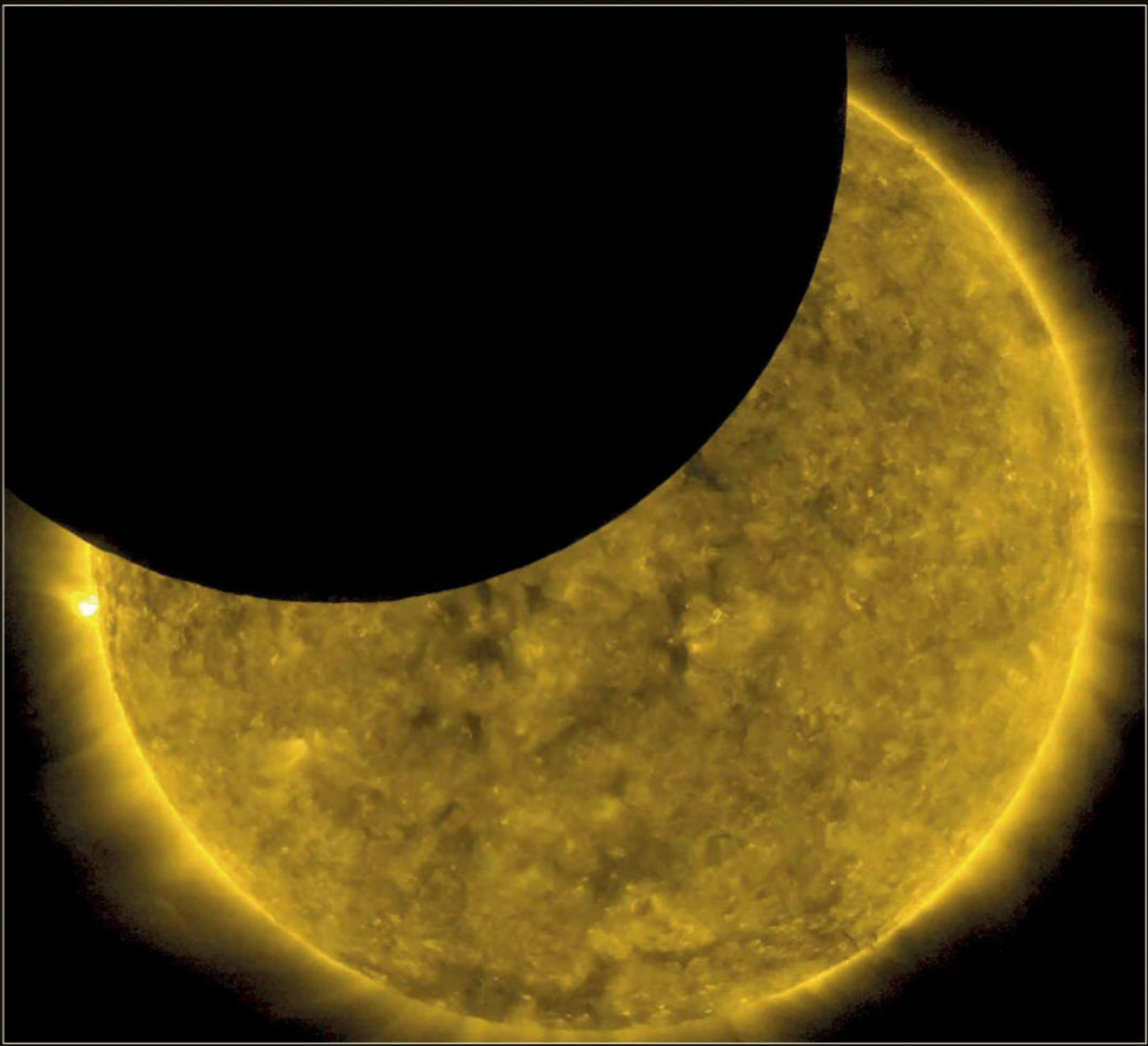
VERY LARGE TELESCOPE, 19 NOVEMBER 2018

Astronomers named this star system 'Apep' after the snake-like Egyptian god of chaos, because of the serpentine swirls of cosmic material surrounding the stars. The lower object is actually two Wolf-Rayet stars in a binary system. These old, massive stars are ejecting stellar winds of gas into space, creating dust plumes that collide to form the coiling clouds.

▼ Dark shadow of the Moon

NASA SOLAR DYNAMICS OBSERVATORY, 7 NOVEMBER 2018

The orbiting Solar Dynamics Observatory managed to capture this ultraviolet image of the Moon partially blocking the Sun. NASA scientists can study the sharp edge of the lunar shadow to measure how light diffracts around the telescope's optics, and thereby fine-tune the instruments for sharper observations.



Bulletin

The latest astronomy and space news written by **Paul Sutherland**

PLUS CUTTING EDGE

Our experts examine the hottest new astronomy research papers

The rocky surface of Barnard's Star b, a barren world where temperatures are –175°C

ESO/M. KORNMESSER

A super-Earth discovered orbiting BARNARD'S STAR

The frozen rocky world lies just six lightyears away

A super-Earth – with a mass of more than three times our planet – has been discovered orbiting Barnard's Star, the nearest star to us after Alpha Centauri's triple-star system.

An international team identified the frozen world using data gathered over 20 years. Dubbed Barnard's star b, or GJ 599 b, it is the second-closest known exoplanet, six lightyears away.

The planet is at least 3.2 times as massive as Earth, and it orbits its red dwarf host star once every 233 days. It is the first time a small world so far from its star has been found using the radial velocity method – measuring the wobble in starlight as a planet orbits.

UK planet-hunter Guillem Anglada Escudé, of Queen Mary University, London, co-led the international discovery team, alongside Ignasi Ribas of Spain. Their find is part of the Red Dots project which focuses on red dwarf stars because they are dimmer with less glare to overwhelm faint planets.

Although the distance between the new world and Barnard's Star is less than half the distance between Earth and the Sun, it gets just a 50th of the warmth. Temperatures are a chilly –170°C, turning volatile compounds such as water to ice. That is too cold for life as we know it. However, Dr Escudé suggests that other sources of heat or a dense atmosphere might make conditions more hospitable.

Astronomers combined observations using high-precision instruments on telescopes around the world to identify the planet. "The combination of instruments was key to allowing us to cross-check our result," says Dr Escudé.

There are hints in the data of another giant gas planet, more like Jupiter, taking more than 10 years to orbit Barnard's Star, but that still has to be confirmed.

The closest Earth-sized rocky planet is Proxima b, which was discovered in 2016.

▸ **See Comment, right**

COMMENT
by Chris Lintott

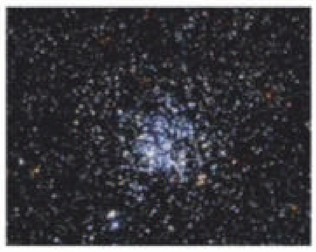
When I was a boy, I remember reading that there were two planets known in orbit around Barnard's Star. This is why Project Daedalus – the British Interplanetary Society's attempt in the 1970s to think seriously about a design for a starship – chose this star as its proposed target.

The planets were 'discovered' by an astronomer called Peter van de Kamp, who looked for tiny changes in the star's position on the sky. In 1963, he announced that he'd found a regular pattern which was due to a planet orbiting the star every 25 years. By 1969 he was able to announce a second world, this one nearly the size of Jupiter.

Sadly, the observed effects were shown to be caused by tiny changes in the instruments over decades. Still, hearing about these planets reminded me how long astronomers have been planet-hunting – and how lucky we are to watch while such discoveries are really happening.

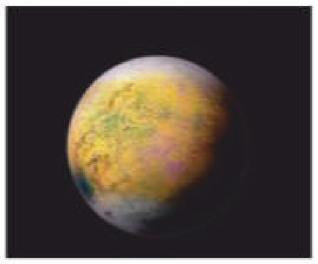
CHRIS LINTOTT co-presents *The Sky at Night*

NEWS IN BRIEF



WHEN BLACK HOLES MERGE

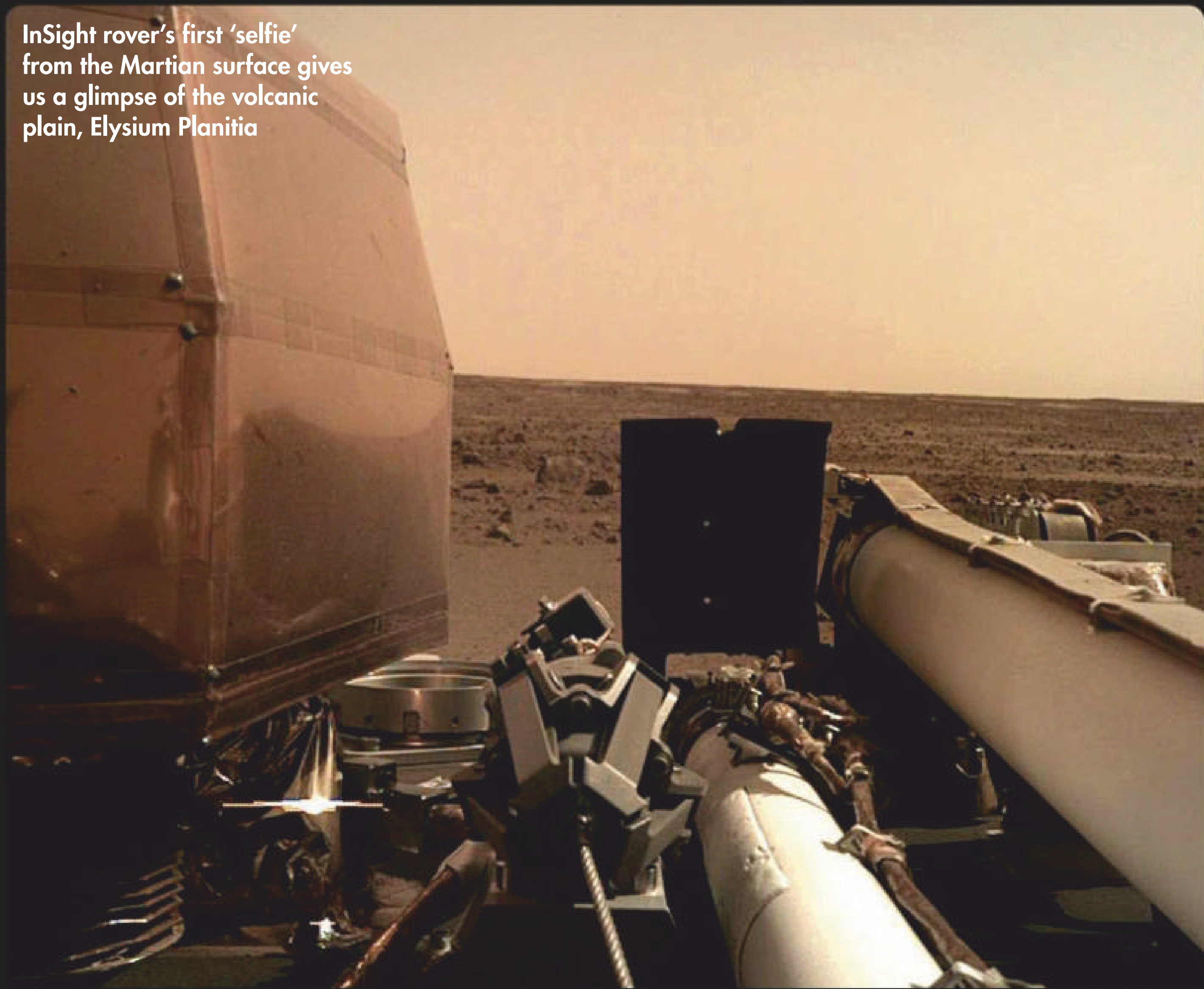
A pair of supermassive black holes are closing together in separate colliding galaxies, giving astronomers their best ever view of such a merger. In a tangled mass of dense gas and dust, the two behemoths are set to coalesce into one mega black hole, an event ready to be captured in near-infrared images using adaptive optics at the WM Keck Observatory on Hawaii. The two galactic nuclei glow brilliantly as the black holes gorge on gas from merging galaxy NGC 6240 in Ophiuchus.



WILD DUCK CHASE ENDS

Astronomers have solved the riddle of how stars in a single cluster can be different colours – suggesting different ages – when they would be expected to have been formed together. A Korean and Belgian team studied the Wild Duck Cluster, M11, made up of around 2,900 stars, with the University of Arizona's MMT telescope. By examining the stars' spectra – using data from splitting star light – they found the range of colours is down to different rates of rotation, not age.

ROBERTO MOLAR CANDANOSA AND SCOTT SHEPPARD, COURTESY OF CARNEGIE INSTITUTION FOR SCIENCE, ESA IMAGES X2, NASA IMAGES X3



InSight rover's first 'selfie' from the Martian surface gives us a glimpse of the volcanic plain, Elysium Planitia

InSight touches down on the RED PLANET

NASA's latest Mars rover seeks clues about the formation of planets

NASA's InSight probe landed safely on Mars on 26 November to begin its investigation into what lies deep beneath its surface and to discover how it and other planets formed.

InSight descended through the atmosphere in six and a half minutes to settle on a volcanic plain called Elysium Planitia, near the Martian equator, becoming NASA's eighth mission to make a successful soft landing on the Red Planet. Unlike Curiosity rover, the previous mission to land in 2012, InSight will not roam the planet, but study Mars from a fixed position.

InSight – short for Interior Exploration using Seismic Investigations, Geodesy and Heat Transport – touched down just before 19.53 UT after a 485 million km journey. Within the next six hours, the lander opened its two 2.2m-wide solar panels to collect sunlight and keep its batteries charged. It also sent home the first image of its surroundings, which appeared to be smooth in the immediate area but strewn with rocks in the near distance (see above).

In the days ahead, InSight's robotic arm is due to be unstowed and extended so that a camera can photograph the ground to help engineers choose where to place its scientific instruments.

These include a dome-shaped seismometer called SEIS (the Seismic Experiment for Interior Structure) which will measure pulses from marsquakes and meteorite impacts. Another instrument, HP3 (the Heat Flow and Physical Properties Probe), is a burrowing probe contributed by the German Aerospace Center (DLR) which will dig 5m into the subsoil to measure heat coming from the planet's interior and find out whether Mars still has a molten core.

It will take two or three months to deploy the experiments, during which time InSight is due to take readings with its weather sensors and magnetometer. Its mission is scheduled to last 709 sols (Mars days), or nearly two Earth years.

Meanwhile, landing sites have been selected for the next Mars rover missions, launching in 2020. NASA has chosen Jezero Crater, on the edge of giant impact basin Isidis Planitia, while sediment-rich Oxia Planum has been recommended for ESA's British-built ExoMars rover.

mars.nasa.gov/insight

NEW HORIZONS ON TARGET

▲ An artist's impression of New Horizons and the Kuiper Belt object (486958) 2014 MU_{69}, less formally known as Ultima Thule

NASA's New Horizons space probe has been swiftly closing in on Ultima Thule, an object in the Kuiper Belt 100 times smaller than Pluto. The most distant encounter ever with a Solar System body will come on 1 January 2019.

New Horizons, which visited Pluto in July 2015, began sending back images in November to help mission controllers at the Johns Hopkins University Applied Physics Laboratory find potentially hazardous moons or rings in its path. Its closest approach to Ultima Thule, at 05.33 UT on New Year's Day, will be just 3,500km.

Officially named (486958) 2014 MU_{69}, Ultima Thule orbits 1.5 billion km beyond Pluto and will offer clues to the formation of the Solar System.

"It likely represents the best sample of the ancient Solar Nebula ever studied," says principal investigator Alan Stern. "Nothing like it has ever been explored."

pluto.jhuapl.edu

▸ **Read more from Alan Stern on page 106**

Gaia spots ghost of a galaxy

Our new neighbour, Ant 2, is a third the size of the Milky Way

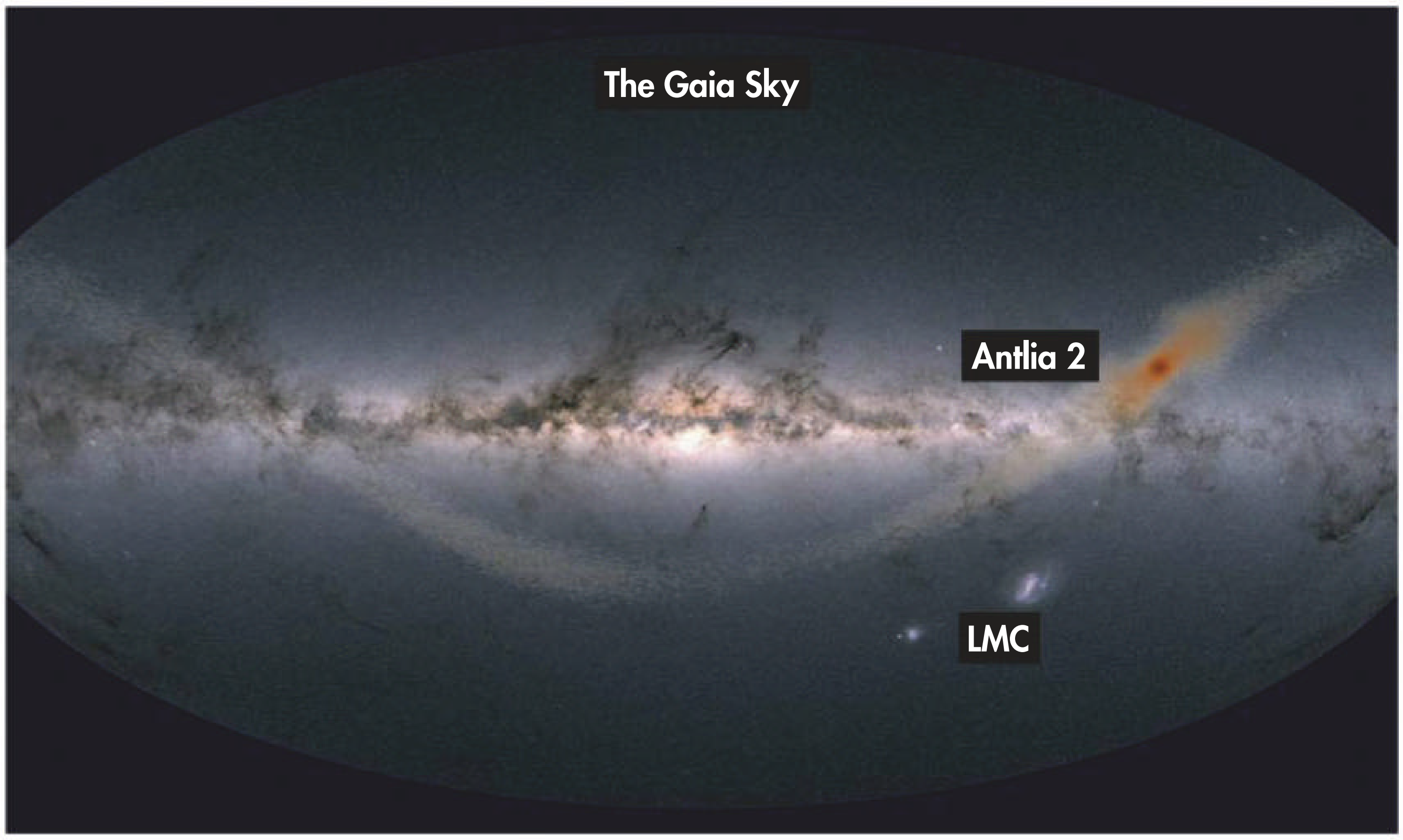
Our Galaxy has a vast ghostly neighbour hidden from view, astronomers have discovered. It's a third the size of the Milky Way, but too dim to be seen through it.

An international team, including researchers from the University of Cambridge, identified the galaxy using data from ESA's Gaia mission. It has been named Antlia 2, or Ant 2 for short.

It's a dwarf galaxy, the first type to form in the Universe, which astronomers found by checking for RR Lyrae variable stars and finding several moving through the sky together. 130,000 lightyears distant, it is bigger than the Large Magellanic Cloud, but 10,000 times fainter. Scientists believe it lost mass due to the tidal pull of the Milky Way but are puzzled by its size.

"This is a ghost of a galaxy," says Gabriel Torrealba, from Taiwan's Academia Sinica in Taipei. "Objects as diffuse as Ant 2 have simply not been seen before."

ast.cam.ac.uk/~vasily/antlia2/info.html



▲ The orange stars show a computer model of Antlia 2 in relation to the Milky Way, which it lies beyond

NEWS IN BRIEF

SUN'S TWIN LOCATED

The Sun's identical twin has been discovered 184 lightyears away in the southern constellation of Pavo. Astronomers in Portugal scoured a database called AMBRE, which lists thousands of nearby stars, to find ones of similar age that might have formed in the same cluster, 4.5 billion years ago. High-resolution spectra, together with Gaia satellite measurements, narrowed candidates down and one, labelled HD 186302, closely matches the Sun's composition and age.

100 HOURS OF ASTRONOMY

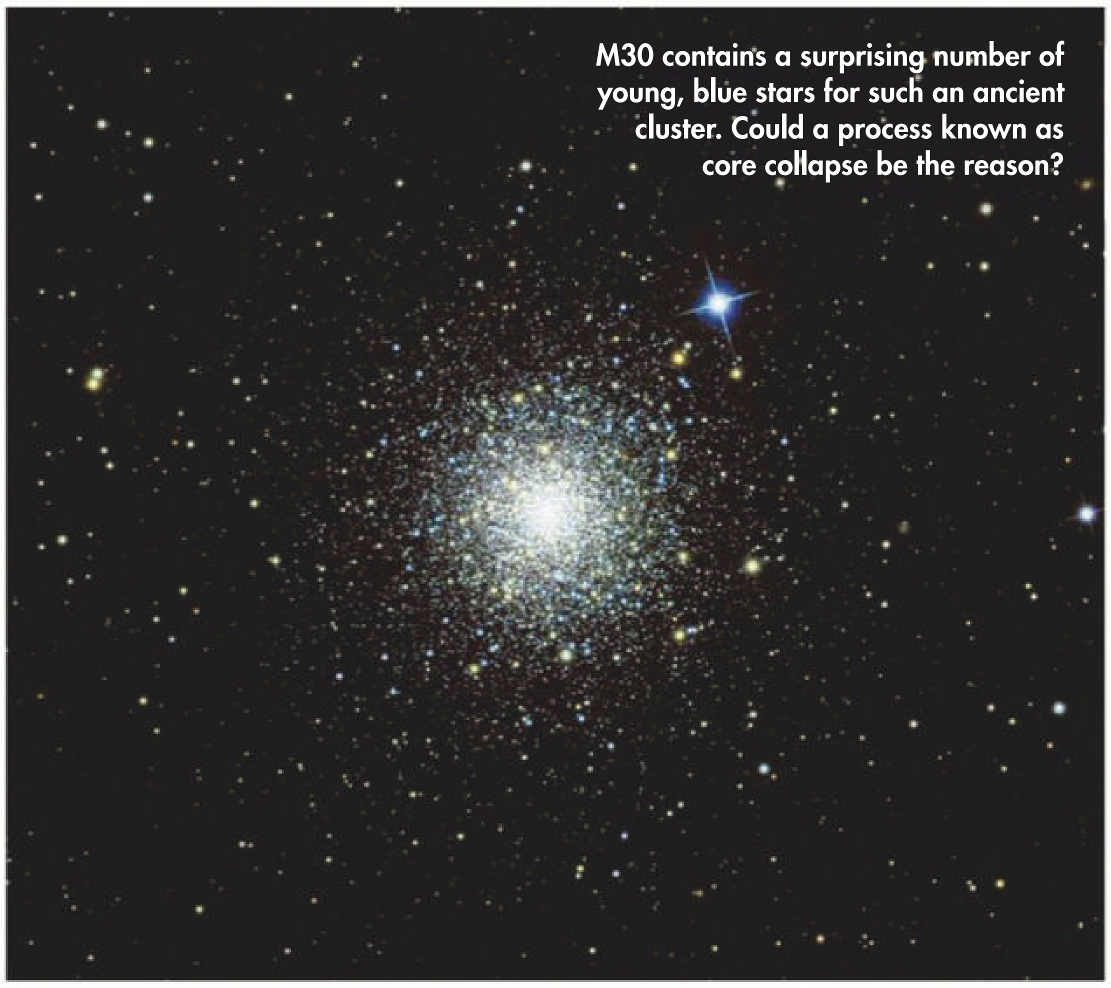
The Society for Popular Astronomy (SPA) is encouraging everyone to look skywards as part of an international 100 Hours of Astronomy event on 10-13 January. The main focus will be the Moon, which will grow from crescent to first quarter phase over those days. "Anyone with a clear sky can pick out a few features, even with the naked eye," says SPA president Robin Scagell. "So why not invite neighbours or friends round for a look through your scope?" See **www.popastro.com** for more details.

CUTTING EDGE

Our experts examine the hottest new research

Young stars in an old neighbourhood

Some star clusters are much bluer than expected


M30 contains a surprising number of young, blue stars for such an ancient cluster. Could a process known as core collapse be the reason?

Not all star clusters are the same. Look at an open cluster like the Pleiades, for example, and you will see a host of brilliant blue stars. On the other hand, if you turn your attention to a globular cluster, such as M30 in the constellation of Capricornus, you'll be looking at some of the oldest stars the sky has to offer; young, blue stars are conspicuous by their absence, and these sprawling stellar cities are populated only by redder stars.

Things would once have been different. We think all the stars in a cluster form at the same time, so if you'd looked at M30 some 12 billion years ago, you'd have seen both blue and red stars. The blue stars are more massive, and so the enormous temperatures and pressures at their cores mean that they run through their supply of hydrogen fuel more quickly than their smaller siblings. In turn, that means they leave the main, hydrogen-burning sequence more quickly and reach the end of their lives much sooner. By looking at the most massive stars that still survive within a given cluster, astronomers can work out its age.

Or at least, they should be able to. Nothing is ever quite that simple. Look closely at any large globular cluster, and you'll find there's a small population of blue stars scattered in amongst the main, red population. These stars, which seem to be behind the pace with which the rest of the population is evolving, are called 'blue stragglers', and a recent paper by Simon Portegies Zwart in Leiden tries to explain where they come from.

There are two main ideas, both of which suggest that the stragglers are the products of violent mergers between two stars. If two smaller stars are in a tight enough binary they will, over time, spiral in toward each other and eventually merge. The result will be the apparently sudden appearance of a massive, and therefore blue, star, seemingly from out of nowhere.

"Look closely at any large globular cluster and you'll find there's a small population of blue stars called 'blue stragglers'"

The other route to a merger is even more dramatic. There are thousands of stars in a cluster like M30, and direct collisions between them are not unheard of, especially when the cluster has undergone a process known as core collapse. During this process, which can happen billions of years into the life of a cluster, close encounters between stars lead some to migrate to the cluster's outskirts while the core becomes denser. A denser core means more stellar collisions, and hence more blue stragglers.

Portegies Zwart built himself a computer version of M30, and set it loose to see what would happen. In the model, a binary merger happens about once every 350,000 years, a process which produces about half the blue stragglers we see. The rest form about 9.5 billion years into the cluster's life, the result of sudden core collapse making collisions – for a short time – likely.

In the model, both processes are more efficient than we might expect: they produce 10 per cent more blue stragglers than we see in reality. As a result, the author reckons that there are more stragglers hiding in the cluster, and finding them is a direct challenge for observers.


CHRIS LINTOTT is an astrophysicist and co-presenter of *The Sky at Night* on BBC TV. He is also the director of the Zooniverse project

Chris Lintott was reading... *"The origin of the two populations of blue stragglers in M30"* by Simon Portegies Zwart (Leiden Observatory). **Read it online at: arxiv.org/abs/1811.00058**

CHRIS BUTLER/DANIEL VERSCHATSE_CCDGUIDE.COM

Giant crater found in Greenland

300m deep and 30km wide, it's one of Earth's 25 biggest impact craters

▲ It may not be obvious from this photograph but radar has discovered an impact crater under Hiawatha glacier

A previously unknown impact crater has been discovered beneath Hiawatha Glacier in Greenland.

30km wide, it is one of the 25 largest in the world. It was initially discovered in 2015 as a circular depression in NASA radar data monitoring polar ice. Researchers from the Natural History Museum of Denmark followed up by checking imagery from NASA's Terra and Aqua satellites, then flying over the region with ice-penetrating radar. Their findings were published in November.

They believe it formed when an iron asteroid collided less than three million years ago. Co-investigator Joe MacGregor, of NASA's Goddard Space Flight Center, said: "The survey imaged the depression in stunning detail: a distinctly circular rim, central uplift, disturbed and undisturbed ice layering and basal debris – it's all there."

earthobservatory.nasa.gov

Hubble discovers cluster of clusters

Over 20,000 globular clusters have been spotted in recent images of the Coma Cluster, taken by the Hubble Space Telescope. The find will help astronomers track dark matter throughout the cluster.

Globular clusters are diffuse balls of stars found in the outer regions of galaxies. The Hubble images captured 22,426 globular clusters spread across the Coma Cluster's 1,000 or so galaxies, 300 million lightyears away.

As globular clusters are smaller and more numerous than galaxies, these images will help researchers map the Coma Cluster's gravitational layout. As gravity within a cluster is dependent on both visible and dark matter, such maps will help astronomers understand the role of dark matter within the cluster.

hubblesite.org

▲ A Hubble image showing just a few of the 22,426 globular clusters it captured in the immense Coma Cluster

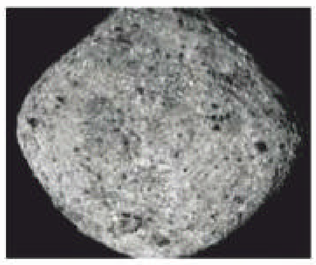
LOOKING BACK THE SKY AT NIGHT

10 January 1979

On 10 January 1979 *The Sky at Night* reported on six American and two Russian spacecraft that had recently reached Venus. Our inner neighbour in the Solar System is overwhelmingly hostile, with its dense atmosphere, searing hot surface and clouds of deadly sulphuric acid. The Soviet Union had sent a number of Venera landers since 1970, which sent back pictures of a rock-strewn surface before being destroyed by the heat and atmospheric pressure. NASA had made two successful flybys with Mariner 2 in December 1962 and Mariner 10 in February 1974. Then, in December 1978 NASA's Pioneer Venus mission arrived, putting a satellite into orbit and firing four probes into the Venusian atmosphere. The Orbiter mapped Venus until crashing into the atmosphere in 1992. Patrick Moore and Dr Garry Hunt discussed the spacecrafts' findings and pondered future exploration of the planet now dubbed Earth's evil twin.

▲ Images of Venus taken by Soviet landers Venera 9 and 10 in 1975

NEWS IN BRIEF



OSIRIS-REX REACHES BENNU

NASA space probe OSIRIS-REx arrived at its new home, the asteroid Bennu, on 3 December 2018. The spacecraft is now orbiting Bennu and will survey the asteroid, measuring its mass, spin rate and shape. OSIRIS-Rex's operators will use this data to create an accurate model of Bennu, which they will then use to determine the best place from which the spacecraft will take a rock sample that will be returned to Earth in 2023. Bennu orbits within the orbits of Earth and Mars.

'BIG BANG' STAR FOUND

What appears to be one of the oldest stars in the Universe, made up almost entirely of material produced in the Big Bang, has been discovered. Part of a binary system, the star is about 13.5 billion years old and in the same region of the Milky Way as the Sun. "This star is maybe one in ten million," says Kevin Schlaufman, assistant professor at Johns Hopkins University. "It tells us something very important about the first generations of stars."

NSSDC, NASA, CENTRE DE DONNÉES ASTRONOMIQUES DE STRASBOURG / SIMBAD / DSS2, NASA/JOHN SONNTAG, NASA/GODDARD/UNIVERSITY OF ARIZONA

CUTTING EDGE

Our experts examine the hottest new research

Can moons have their own moons?

And if they can, then why haven't we found any examples of 'submoons' in the Solar System?

▲ **Research suggests that Titan, Iapetus, Callisto and Earth's Moon could all theoretically be hosts to their own 'submoons'**

NASA/JPL:X3 PETE LAWRENCE

Every now and then you come across a question that is so beguilingly simple, and so obvious in retrospect, that it makes you immediately sit back and think, "Hmm, I wonder…?" For me, this happened recently with a paper written by astronomers Juna Kollmeier and Sean Raymond, in which they asked, "Can moons have moons?"

Conventionally, planets are large bodies that orbit a star, and moons are objects that orbit a planet. But could there be something filling the next pigeonhole down in the hierarchy? Could moons themselves host a large orbiting moon – or a submoon, Kollmeier and Raymond's term.

There aren't any such objects in our Solar System, but that doesn't mean they are impossible, and they could perhaps be common in extrasolar planetary systems. (Although in a strict sense, of course, satellites like the Lunar Reconnaissance Orbiter are indeed moons of our Moon, but they are inconsequentially tiny and artificial.) The challenge facing submoons is the complex gravitational environment they would find themselves in.

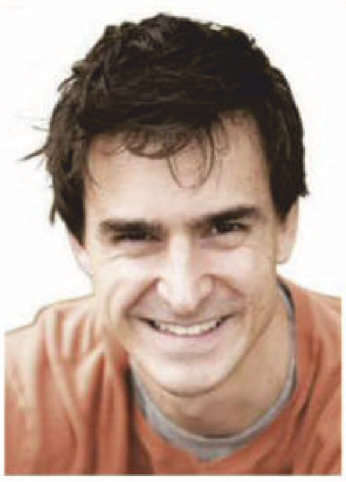
A submoon circling a moon would experience tidal forces – in just the same way that both bodies in the Earth-Moon system do – that would change its orbit over time. Depending on the circumstances, the submoon may migrate in towards its host moon, and eventually crash down onto its surface, or else slowly spiral outwards until it is pulled away entirely by the stronger gravity of the planet. Kollmeier and Raymond have studied this issue of the 'dynamical stability' of different planet-moon-submoon systems to calculate under what ranges of conditions submoons are possible.

What they found is that submoons of around 10km across can only survive around large, 1,000km-scale moons if this host moon is on a wide-separation orbit around its planet. Tidal effects destabilise the orbits of submoons around moons that are too small or too close to their host planet – which is the case for most of the moons in our Solar System. However, Kollmeier and Raymond tantalisingly discovered that a handful of known moons are, in fact, capable of hosting long-lived submoons: Saturn's moons Titan and Iapetus, Jupiter's moon Callisto, and Earth's Moon.

> "The challenge facing 'submoons' is the complex gravitational environment they would find themselves in"

This result immediately raises another fascinating question: if submoons are indeed possible, in terms of orbital stability, why don't we find any? What other causes might have blocked the existence of submoons in our Solar System?

There are two possibilities. In order to actually exist, submoons must have a viable process of formation. The large moons of Jupiter and Saturn, for example, are thought to have coalesced out of a disc of material swirling around the planet, but perhaps submoons can't form at the same time. Or, if primordial submoons did actually form around Titan, Iapetus, Callisto or our Moon, they must have been removed later – possibly disrupted by the orbital migration of their host moon. (Our Moon, for example, has been spiralling slowly away from the Earth ever since its formation.) Either way, the apparent non-existence of submoons in our Solar System is revealing. Their absence provides clues, say Kollmeier and Raymond, to the formation mechanisms of the large moons in the Solar System, and their orbital history over time.



LEWIS DARTNELL is a professor of science communication and the author of *The Knowledge: How to Rebuild our World from Scratch* (Penguin, 2014)

LEWIS DARTNELL was reading… *Can Moons have Moons?* by Juna A Kollmeier and Sean N Raymond. **Read it online at: arxiv.org/abs/1810.03304**

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Autumn & Winter 2018
The winter skies are returning. Time to plan ahead for the winter's observing and astrophotography! With the end of summertime, and sunset and the Pleiades rising around 4.30pm at the beginning of the month, there;s lots to see. Orion clears the horizon around 10pm. The Widescreen Centre is a real showroom you can visit and see the latest priduwhich cts and get expert advice before you buy.
Your hobby is important. You want to be sure you're getting the best. Check in with us for events around the country or here at our dark-sky site in Cambridgeshire
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What's on

Our pick of the best events from around the UK

Armagh Planetarium is adjacent to Armagh Observatory, which is also worth a visit

Star Tracker Evening

Armagh Planetarium, County Armagh, 10 January, 7.30pm

A trip to the Armagh Observatory and Planetarium is a must for astronomy and space enthusiasts. Each month until March 2019 the planetarium is hosting family-friendly 'Star Tracker' evenings exploring the wonders of the night sky. The evening begins with a planetarium show in the Dome selected by director Professor Michael Burton and also includes an astronomy talk in the Copernicus Hall.

In January the show will be *Out There: The Quest for Extrasolar Worlds*, a short film about the search for exoplanets produced by The Swiss Museum of Transport Planetarium in cooperation with NCCR PlanetS and the European Southern Observatory (ESO). But the event isn't purely theoretical; visitors will also be able to get incredible views of the Moon and the night sky through Armagh Planetarium's 12-inch Dobsonian telescope (weather permitting).

Tickets for the Star Tracker evenings are £7.50 for adults, £5.50 for children and concessions. There are also group tickets available for families. Spaces for the event are limited, so pre-booking is strongly advised.

To find out more about this month's Star Tracker Evening, or to book tickets and get a full list of future events, visit Armagh Planetarium's website.
www.armaghplanet.com/events

BEHIND THE SCENES

THE SKY AT NIGHT IN JANUARY

BBC Four, **13 January,** 10pm (first repeat BBC Four, **17 January** 7.30pm)*

What will New Horizons' Kuiper Belt flyby reveal about the origins of the Solar System?

BEYOND PLUTO

The New Horizons mission has given us incredible images and data on Pluto. As part of a mission extension, on 1 January the spacecraft will perform the first ever flyby of a Kuiper Belt object on the edge of the Solar System. The *Sky at Night* team reveals the latest news and images from this historic mission.

Check www.bbc.co.uk/skyatnight for subsequent repeat times

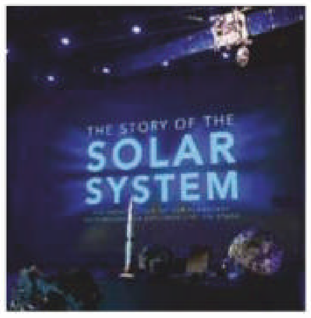
Techniquest North Wales

Glyndŵr University campus, Wrexham, 12 January, 6.30pm

The Techniquest Astronomy Club will be looking beyond the orbit of Neptune this month, tracking the New Horizons spacecraft just after its Kuiper Belt Object flyby on 1 January. They'll also be discussing other dwarf planets in the Kuiper Belt, stepping on to the surface of Neptune via virtual reality and offering guests the chance to take a look through one of their telescopes. Tickets are £5 per person, with a 10 per cent discount for annual pass holders.
www.tqg.org.uk

The Story of the Solar System

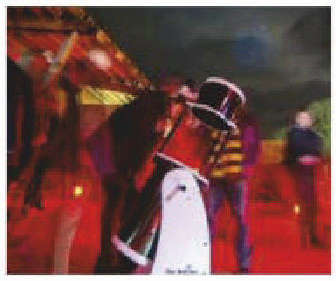
Exeter Phoenix, Exeter, 27 January 2019, 7.30pm



Astronomer and writer Will Gater returns with his live show explaining the origins and evolution of our cosmic neighbourhood. Expect on-stage demos and stunning astrophotography as Gater relates the story of the planets, moons, asteroids and comets that orbit the Sun. Tickets are £12 or £10 for concessions. For more info and to check for extra tour dates, visit Will Gater's website.
www.willgater.com/solarsystem/

Family astronomy evening

The Sill, Northumberland National Park, 5 January, 6pm

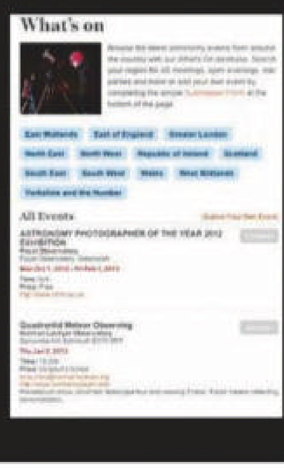


Two events are being held this evening at the National Landscape Discovery Centre, teaching families and beginners how to observe the night sky. A 'Family Astronomy' session begins at 6pm with demonstrations on how to use telescopes and binoculars, while a later session at 8pm invites newcomers aged 11 and above to join the Go Stargazing team for practical astronomy through telescopes. Tickets are £10 and £12 respectively. To book, visit the park's website.
www.northumberlandnationalpark.org.uk/whats-on

MORE LISTINGS ONLINE

Visit our website at **www.skyatnightmagazine.com/whats-on** for the full list of this month's events from around the country.

To ensure that your talks, observing evenings and star parties are included, please submit your event by filling in the submission form at the bottom of the web page.



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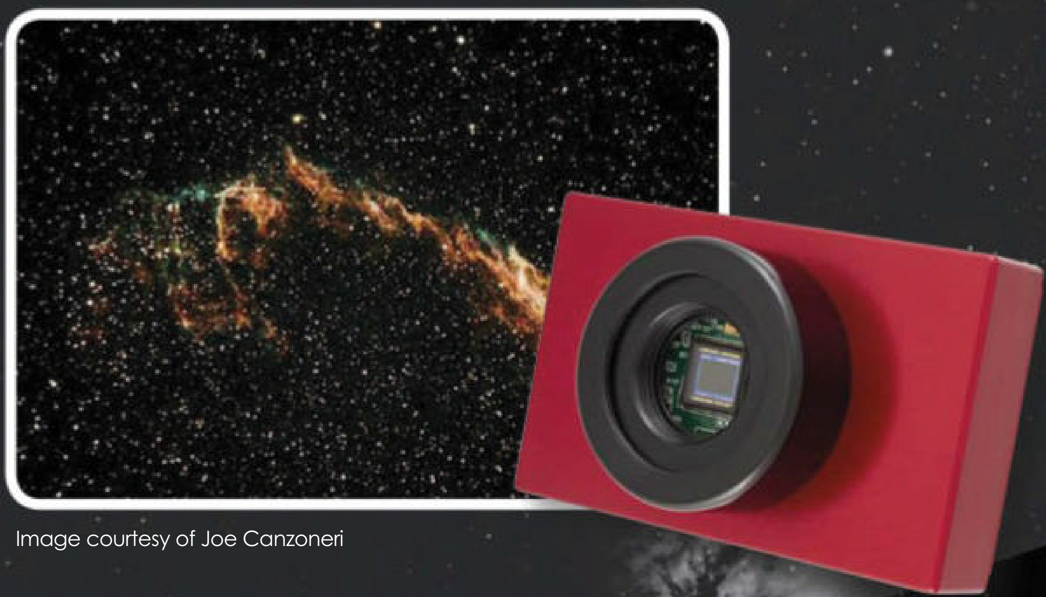

Image courtesy of Joe Canzoneri

Perfect for the entry- level astronomer, the Atik Infinity is the first Atik CCD camera dedicated to video astronomy. It is supplied with our new, intuitive, in-house software dedicated to video astronomy, and is well suited to a broad range of telescopes, bringing the wonders of deep-sky imaging to your screen in just seconds.

Atik Infinity
Entry level

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Atik 460EX
Mid range

Image courtesy of George Chatzifrantzis

The Atik 460EX is renowned for its perfect balance of sensitivity and resolution. It utilises a Sony ICX694, which is the sensor of choice for astronomers looking for the highest-quality data. Its efficiency and generous sky coverage make the 460EX one of the most versatile astrophotography cameras around, ideal for a large range of telescopes.

Atik 16200
Large Format

Image courtesy of
MASIL Imaging Team

The Atik 16200 boasts a sensor specifically designed for astronomy and having a generous 35mm diagonal. The 16million, 6μm pixel sensor can be freely binned so offers a huge amount of flexibility for both wide field and long focal length imaging. Argon purging, deep cooling and a mechanical shutter make this a camera for professionals and amateurs alike. The Atik 16200 is the camera capable of taking your imaging to the next level.

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A PASSION FOR SPACE

with **Dr Kimberly Ennico**

High-tech flying observatory SOFIA soars into the stratosphere to peer into the Universe in infrared

Scope on a plane – SOFIA is housed in a Boeing 747SP

NASA/THOMAS

The world's premier flying observatory is unravelling the mysteries of our Universe by studying fundamental processes affecting the formation of stars, planets and galaxies. SOFIA (the Stratospheric Observatory for Infrared Astronomy) features a Hubble-sized telescope in a modified Boeing 747SP, flying high into Earth's stratosphere (12km) to enable us to study the infrared Universe.

But why infrared? Over half of the 'light we see' in the Universe is radiation that has been absorbed by dust and re-emitted at infrared wavelengths. Much of the space between stars is filled with atomic and molecular gas – mainly hydrogen and helium – and tiny pieces of dust (solid particles), composed of heavier elements like carbon, oxygen and silicon. By observing the infrared light we are seeing both the ingredients for new stars – gas and dust – and leftover dust that has been created by both stellar birth and death.

Constantly cutting-edge

We still do not know how, when and where stars form. We have a rough idea but the variety of star-forming regions seen today indicates it is a complicated process. SOFIA employs a suite of instruments to tackle the underlying triggers or inhibitors of star formation. By periodically changing its equipment SOFIA reaps the benefits of cutting-edge technology.

For example, the GREAT (German REceiver for Astronomy at Terahertz frequencies) spectrometer is ideally suited to measuring spectral lines in a variety of star-forming environments. This improves our knowledge of how stars form at the earliest stages, specifically by looking at gas in molecular clouds. With GREAT, we can observe emissions from ionised carbon and atomic oxygen to understand shocks, thermal conditions and collapsing motions of gas that can form new stars.

Additionally, GREAT hunts for small molecules called hydrides, the basic building blocks of chemical pathways in our Universe, to probe the physical conditions in these clouds.

SOFIA's new polarimeter, HAWC+ (High-resolution Airborne Wideband Camera-plus), can map magnetic fields on the scales of star-forming clouds and 'snake-like' filaments. Spinning dust grains aligned in the presence of magnetic fields emit polarised light. HAWC+ detects this and derives the geometry – and perhaps strength – of surrounding magnetic fields. We are on the verge of observational evidence that can tell us whether magnetic fields help guide gas flowing onto filaments to a point where they become unstable and initiate gravitational collapse to form stars, or if they prevent clouds from collapsing to form stars. Is the Holy Grail of understanding star formation within our reach?

Next year, a new spectrometer called HIRMES (HIgh Resolution Mid-infrarEd Spectrometer) will study planet-forming systems to inform us how water is created, destroyed and eventually delivered to solid bodies. With each step in understanding how stars and planets form, we get closer to understanding our Sun and Earth's origins.

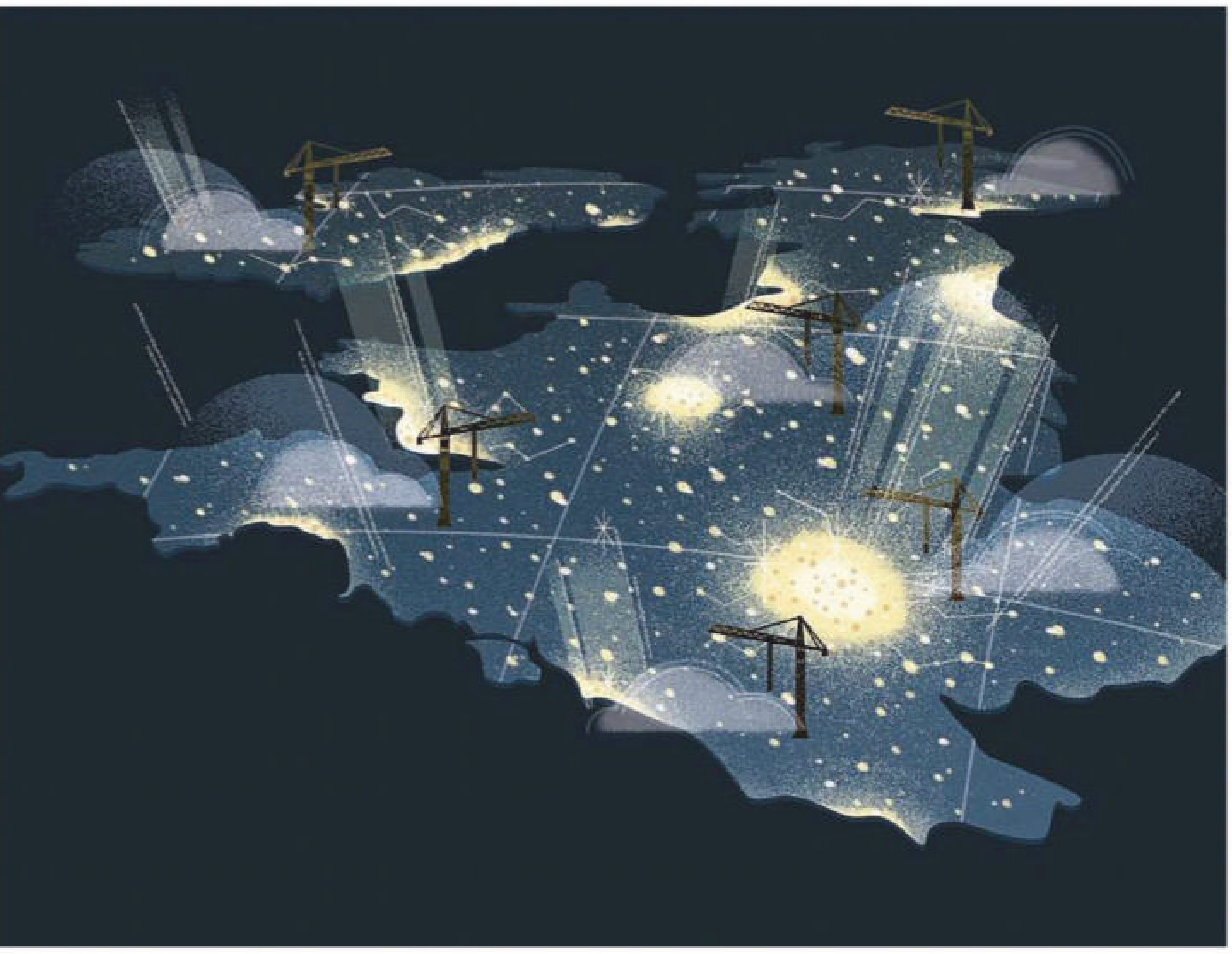
This marvel of an airplane-mounted telescope, unaffected by light turbulence, equipped with a high-tech instrument suite and able go wherever the science demands, brings new perspectives in pursuit of astronomy's most ancient questions.

Dr Kimberly Ennico is a multidisciplinary research astrophysicist at NASA and the SOPHIA mission's project scientist. For more information visit sofia.usra.edu

FIELD OF VIEW THE AMATEUR ASTRONOMER'S FORUM

Dark matters

Tim Jardine laments the fact that light pollution is condemning our night skies to a relentless bleaching



WEITONG MAI/FOLIO ART

Every year I take a trip away from my light-polluted, urban skies to a star party at a dark-sky site. Every year I meet the same people, and every year we stand in the same part of the field, cold hands in pockets, musing over the same topics in the dead of night. There is something cosy about the familiarity of it all.

And one question that always comes up as we gaze skywards is, "Do you think it's as dark here as it used to be?"

The answer to this question is usually anything but comforting, as the glow in the sky from surrounding villages and towns appears to creep higher and brighter than the year before. In fact, as we made the journey to the star party this year, the amount of building work taking place around each settlement on the map was staggering; new houses seemed to be popping up everywhere. Houses that were once on the very edge of town are now surrounded by new developments.

Of course, there is a need for new housing in the UK, nobody would dispute that. The worry, from an amateur astronomer's point of view, is the effect all these new properties will have on overall light pollution, as there'll be more streetlights and other new sources of light in previously dark areas.

While controlled LED lighting and street-light switch-offs help to reduce overall skyglow, the inescapable conclusion is that where new houses replace undeveloped fields, the skies are not as dark. So when we look at statistics released by the Department for Communities and Local Government and see that the number of dwellings in the UK increased by 800,000 homes in the 2012-2017 period, with an even greater number planned by 2020, perhaps it's no surprise that our skies are deteriorating.

Satellite surveys published by the American Association for the Advancement of Science back this up: radiance (artificial light shining or directed upwards) from light pollution in the UK alone rose around 2 per cent annually between 2012 and 2016, and a whopping 9.1 per cent globally.

There is a great irony in all this. The 21st century has seen remarkable advances in the astronomy equipment available to amateurs. From cooled CCD cameras, to cheap Go-To mounts and even affordable large refractors and Ritchey-Chrétien optics, today we really do have some brilliant kit within our reach. What a desperate shame that as the equipment we can use gets better, the skies we use it on get worse. I often imagine a scenario where the father of observational astronomy, Galileo, is somehow alive and in my observatory. I can just imagine his face as he marvels at Saturn's rings, Jupiter's storms and the polar caps of Mars. Then we use a camera to observe whirling galaxies, intricate supernovae remnants and blooming hydrogen clouds. Almost hugging the telescopes he declares "This equipment is amazing, fantastic, I love it, but tell me, what on Earth happened to the beautiful sky? It used to be so dark."

I'm still working on an answer to his question that doesn't give him the impression that humankind has gone completely mad. Ⓢ

TIM JARDINE is an experienced amateur astrophotographer whose work you can see online at **www.astrobin.com/users/timjardine/**

Interactive

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Email us at **inbox@skyatnightmagazine.com**

This month's top prize: four Philip's books

PHILIP'S The 'Message of the Month' writer will receive four top titles courtesy of astronomy publisher Philip's: Robin Scagell's *Complete Guide to Stargazing*, Sir Patrick Moore's *The Night Sky*, Mark Thompson's *Stargazing with Mark Thompson* and Heather Couper and Nigel Henbest's *2019 Stargazing*.

Winner's details will be passed on to Octopus Publishing to fulfil the prize

Tales from THE EYEPIECE

This month's tale comes from West Midlands observer Mary Harrison

Several years ago while touring the mountainous regions of central Spain, my husband and I dined at a restaurant al fresco, taking in the evening scenery. In a flash, it dawned on me that Mercury was undergoing a favourable evening elongation. True enough, there it was, sparkling brightly in the sunset, positively shouting out to be admired! All the other guests were quite unaware of what was passing before their eyes and I felt like going around, telling them what a rare and special thing was right in front of them. When I think of the years I've spent trying in vain to see Mercury through the gloom in the UK it was incredible to have the innermost planet just sitting there. But it seems it was only us two who could truly appreciate it.

Email your own tales at: talesfromtheeyepiece@themoon.co.uk

MESSAGE OF THE MONTH

Prisoners' plan for Mars

A Martian base conceived by prison inmates in a unique project

I am currently a prisoner at HMP Glenochil and I have always had an interest in astronomy. As prisons are places where the night heavens are masked by floodlights, I haven't seen a star in many years. Yet I have recently been involved with a fascinating project which enlisted the unique experiences of prisoners to aid thinking on the best way to establish a base on Mars. Leading scientists from the University of Edinburgh delivered a four-part programme of scientific information and discussion, while prisoners set up groups to develop ideas around the survival and development of a colony in a wholly alien environment. Depending on skills and interests, prisoners worked on topics including science and engineering, music, plant life and politics. The whole project was brought together in a book called *Life Beyond: From Prison to Mars*, which was praised by the British Interplanetary Society, who then published the findings. Even though the stars are cut off to me, I still watch *The Sky at Night* every month. After all, I still have the Moon (sometimes).
Jamie, HMP Glenochil

What a fascinating and worthwhile project, Jamie. For those interested, Life Beyond *is published by the British Interplanetary Society, price £6.* ***– Ed***

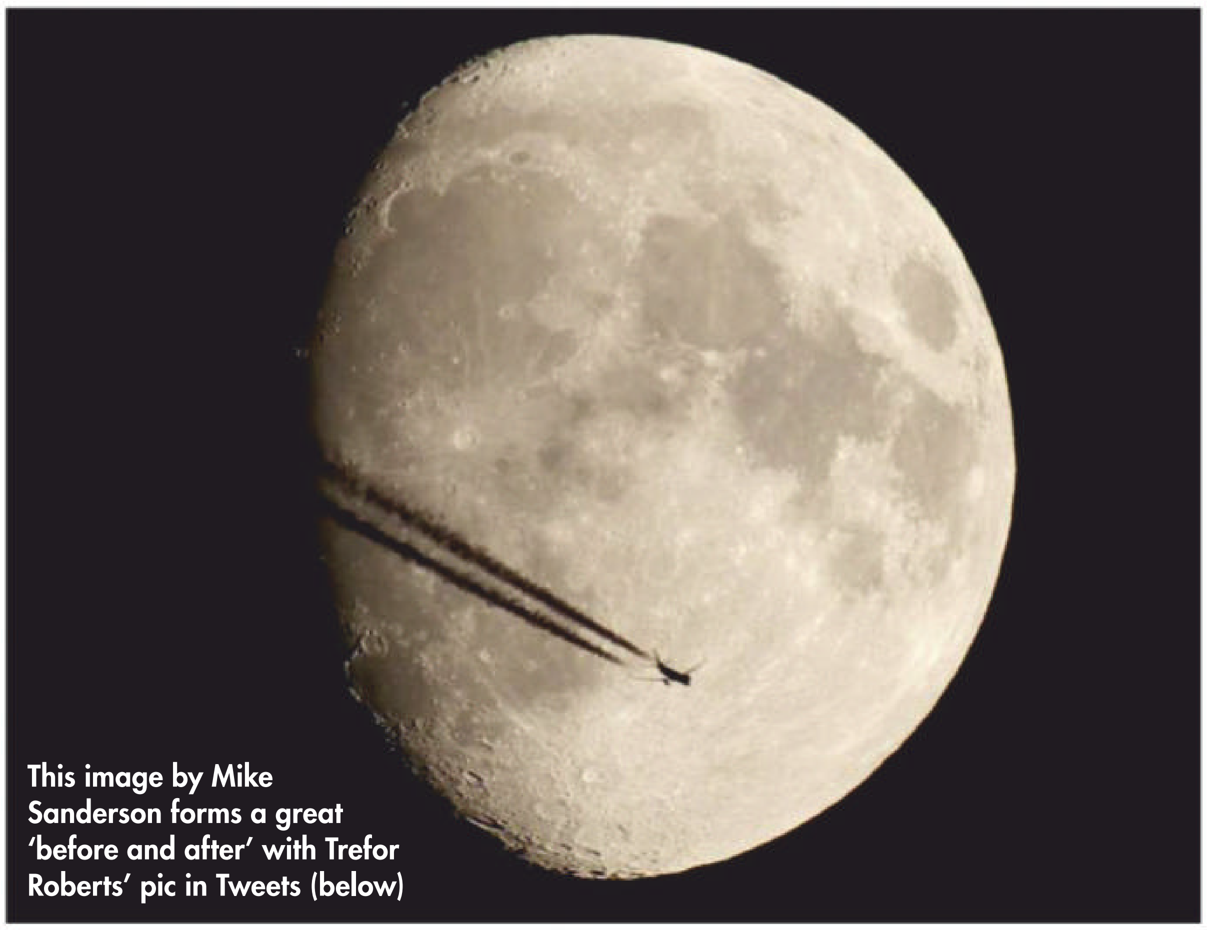
An eye for detail

On page 36 (*Interactive*, November 2018), you mention that "you can glimpse M31… with the naked eye". I live in a relatively dark site in an isolated village and there's no way I can see Andromeda with the naked eye. Even with 20x80 binoculars it can be difficult.

There must be many people like me whose night vision isn't up to much. I'm the better side of 60, had cataracts removed last year and only have to wear glasses to read small print. I can't see the Pleiades with my naked eye, but just know where to point my binoculars/telescope. I think

Tweets

Trefor Roberts
@border70 • Nov 18
@skyatnightmag that was close. Must have missed it by a fraction of a second.



This image by Mike Sanderson forms a great 'before and after' with Trefor Roberts' pic in Tweets (below)

articles like this can raise expectations too high and may frustrate newcomers.
Robert Stewart, Akeley, Bucks

Moon with a croon

I took this picture (above) with my Canon M50 using an Altair Astro Starwave 70 ED refractor. It brings to mind the famous Frank Sinatra song lyric, "Fly me to the Moon, and let me play among the stars."
Mike Sanderson, via email

A software option

Steve Richards suggests an Atmospheric Dispersion Corrector to do away with colour fringing in planetary images (*Scope Doctor*, October 2018). While this is the ideal solution there are a couple of software measures that can partially solve the problem – with the benefit of being absolutely free!

On the Wavelet screen of the freeware program RegiStax there is an 'RGB align' function (using red, green and blue light elements) that will remove the worst of the fringes and improve the overall image.

If your photo manipulation program includes an option to split an image into separate R, G and B channels, you can create a selection around each of the resulting greyscale images and nudge them separately so that, when recombined, they now line up. In effect, this is similar to the RegiStax method but it also allows you to individually tweak the R, G and B channels.
Bob Humphrey, via email

SOCIETY in focus

Aberdeen Astronomical Society (AAS) recently held an open evening (on 13 November) welcoming anyone interested in learning more about the night sky and how to observe it. The event was well received with 60 attendees. The aim is to help people understand various aspects of astronomy by presenting it in a structured yet informal way, while encouraging interaction. The meeting was held at one of our regular venues, Robert Gordon's College in central Aberdeen.

The evening was divided into four parts: a presentation on what can be seen in the night sky at this time of year; a talk on solar observing, showing both types of scope you can use and safe ways to view the Sun; a talk on astronomy basics; and finally, a demonstration of the different telescope types. As some AAS members are keen astrophotographers, the latter talk included examples of photos taken through one of the telescopes on display.

AAS was founded in 1969 and currently has 45 members. The society holds two meetings each month from September to May with one meeting per month for the rest of the year.

The society is keen to welcome new members and help people get the most out of learning about the night sky and using astronomical equipment. AAS also has access to a dark-sky site: just 20 miles from Aberdeen but dark enough for incredible night-sky views. So, if you are a visitor to Aberdeen or live locally and are keen to learn more about astronomy, look us up on our website: **aberdeenastro.org.uk**.

Neville Brown, committee member, Aberdeen Astronomical Society

Meanwhile on FACEBOOK...

WE ASKED: What are you most looking forward to in 2019?

David Jones
A clear night that coincides with any astronomic event.

Peter McNulty
'Oumuamua to land on Earth and scan the planet for intelligent life.

Keith Mountjoy
Mercury's transit of the Sun.

Carolyn Alexander
The 50th anniversary of the Moon landing and Neil Amstrong's famous words.

AR Gavin
New Horizons' flyby of Ultima Thule, the most distant object ever visited by a spacecraft.

Simon Bell
It has to be Solarsphere. What a great, fun experience catching up with friends, learning, laughing and looking. It's a party with the stars.

Stephen Cheatley
I'm really hoping to see the total solar eclipse in Chile and Argentina. I will definitely be including a visit to the Atacama Desert.

Mick Cassidy
Hopefully 2019 will see my first visit to Skellig Star Party, Ireland's gold-tier dark-sky reserve.

Tony Moss
A really clear night to enjoy stargazing would be enough for me.

Mark Prosser
I hope to catch the Northern Lights in Elan Valley as I think it's so magical.

OOPS!
On page 56 of the December 2018 issue, the recommended equipment for viewing Mars should have been an 8-inch or larger telescope, not a 28-inch or larger. On the same page, the best time to see Mars should have been 1 December, 18:20 UT, not 06:20 UT.

Hotshots

This month's pick of your very best astrophotos

YOUR BONUS CONTENT

A gallery containing these and more of your stunning images

▲ The Soul Nebula

DUAN YUSEF, ESSEX, 23 SEPTEMBER-9 OCTOBER 2018

Duan says: "I started shooting this part of the nebula after seeing other photographers' images. There are a lot of wide-field images of this target but this part looked really interesting so I thought I'd try a close-up of the area. I was blessed with over two weeks of clear skies at the end of September so the data just kept rolling in. This is the most exposure time I have ever put into an image and it's ended up being one of the best I've ever taken."

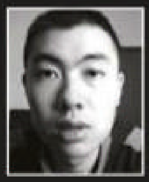
Equipment: ZWO ASI1600 mono camera, Altair Wave 130 EDT apo refractor, Sky-Watcher EQ8 Pro equatorial mount **Exposure:** 140x10′ Hα, 140x10′ OIII; 90x10′ SII **Software:** PixInsight, Photoshop

***BBC Sky at Night Magazine* says:** "Duan's image really leapt out at us when we were looking through the submissions. There's so much going on: glowing nebulosity and thick dark dust; crisp stars and a beautiful blend of colours across the field of view."

About Duan: "I first got into astrophotography about four years ago when I bought a small Go-To telescope, and one night I held my smartphone up to the eyepiece to try to capture a photo of the Moon. I was so impressed with the resulting image that I purchased a DSLR and hooked it up to the scope. The hobby has spiralled out of control since then and I now have a permanent setup in the garden. I love astrophotography because it combines some of my favourite subjects: science, technology and art."

◀ Mars

DAVID XU, MING'ANTU OBSERVATORY, INNER MONGOLIA, 12 AUGUST 2018

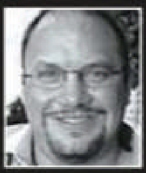


David says: "Mars reached its greatest magnitude this year in July and August, so it was a rare opportunity. It was not demanding to shoot this image, but I'm happy with how it turned out."

Equipment: Canon EOS 6D DSLR camera, Canon EF 16-35mm f/2.8 III USM lens
Exposure: ISO 20,000, 15"

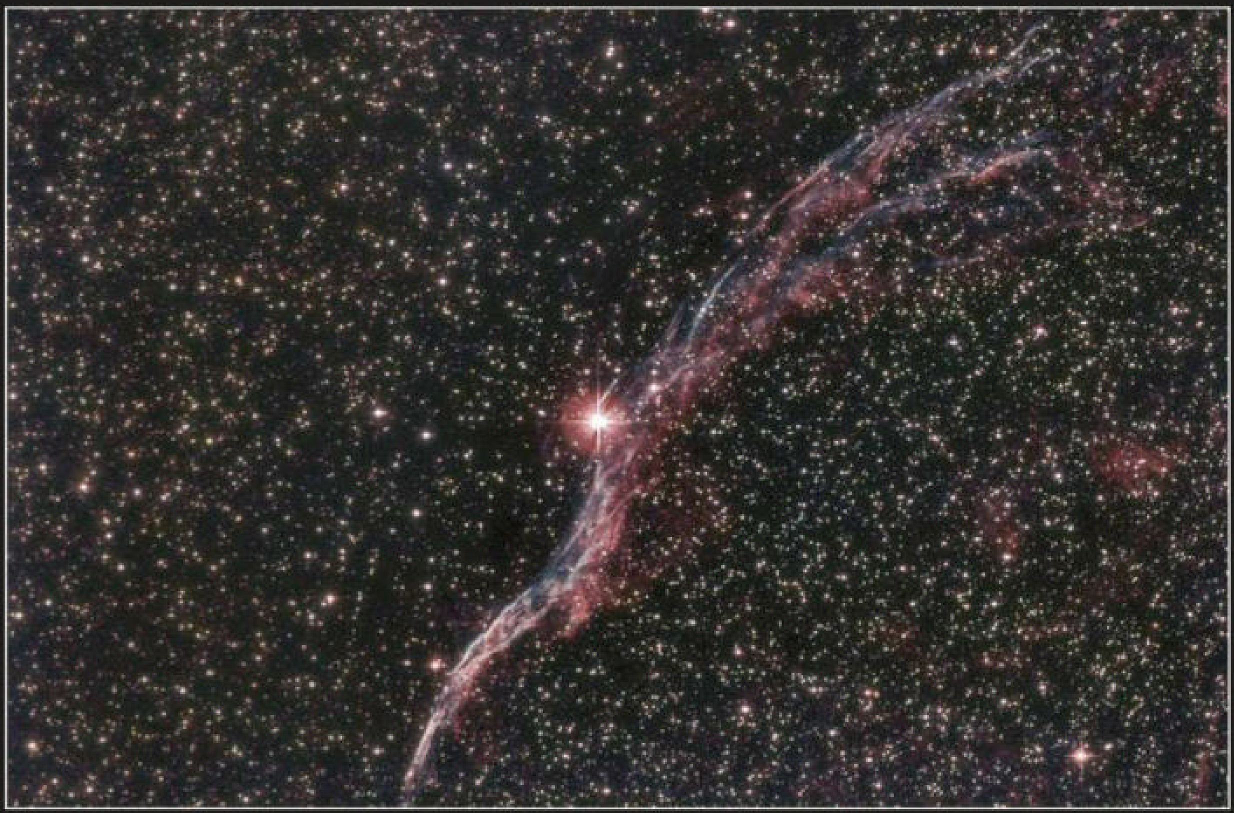
The Witch's Broom Nebula ▶

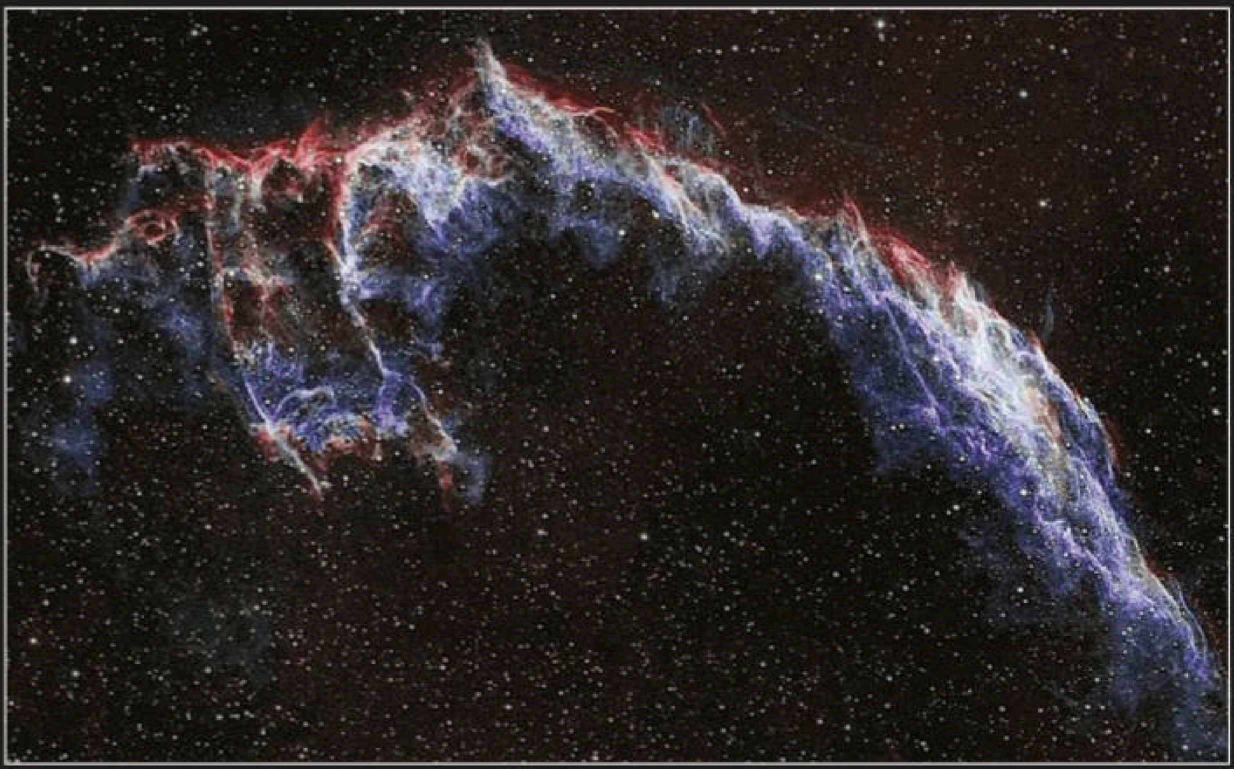
DAVID HARDY, NORTHAMPTONSHIRE, 7 OCTOBER 2018



David says: "I have seen this image so many times in *BBC Sky at Night Magazine* and on various forums so I thought I would have a go at it myself. I am very pleased with the results, although it is still a work in progress and I intend to revisit this and take more subs."

Equipment: Canon EOS 1000D DSLR camera, Sky-Watcher Explorer 200PDS refractor, Sky-Watcher EQ6-R Pro mount
Exposure: ISO 800, 11x300"
Software: StarTools, Photoshop





◀ Cygnus Loop

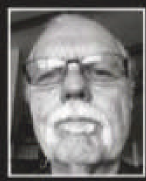
PAUL COLEMAN, BIRMINGHAM, 29 SEPTEMBER, 18 OCTOBER 2018

Paul says: "The Cygnus Loop is a very wide object and I was hoping to test my new ZWO camera out. I'm in a Facebook astrophotography group and enjoy posting my images as I improve."

Equipment: ZWO ASI1600MM mono camera, Revelation ED90 apo refractor, Sky-Watcher HEQ5 Pro SynScan mount **Exposure:** 5x10' Ha, 7x10' OIII **Software:** Sequence Generator Pro, PHD2, PixInsight

The Needle Galaxy

STEVE PASTOR, NEW MEXICO, US, 8, 15, 16 MAY; 17, 18 JUNE 2018

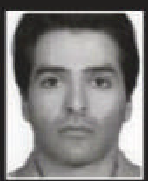


Steve says: "Deep images require several nights of exposures and careful selection of the images to stack. Processing is always a challenge as different objects require different processing tools and settings. I am fortunate to have a permanent observatory in my backyard as well as dark skies."

Equipment: QSI 683 WSG mono CCD camera, Takahashi CCA-250 astrograph, Paramount ME mount
Exposure: 20′ **Software:** MaxIm DL, PixInsight

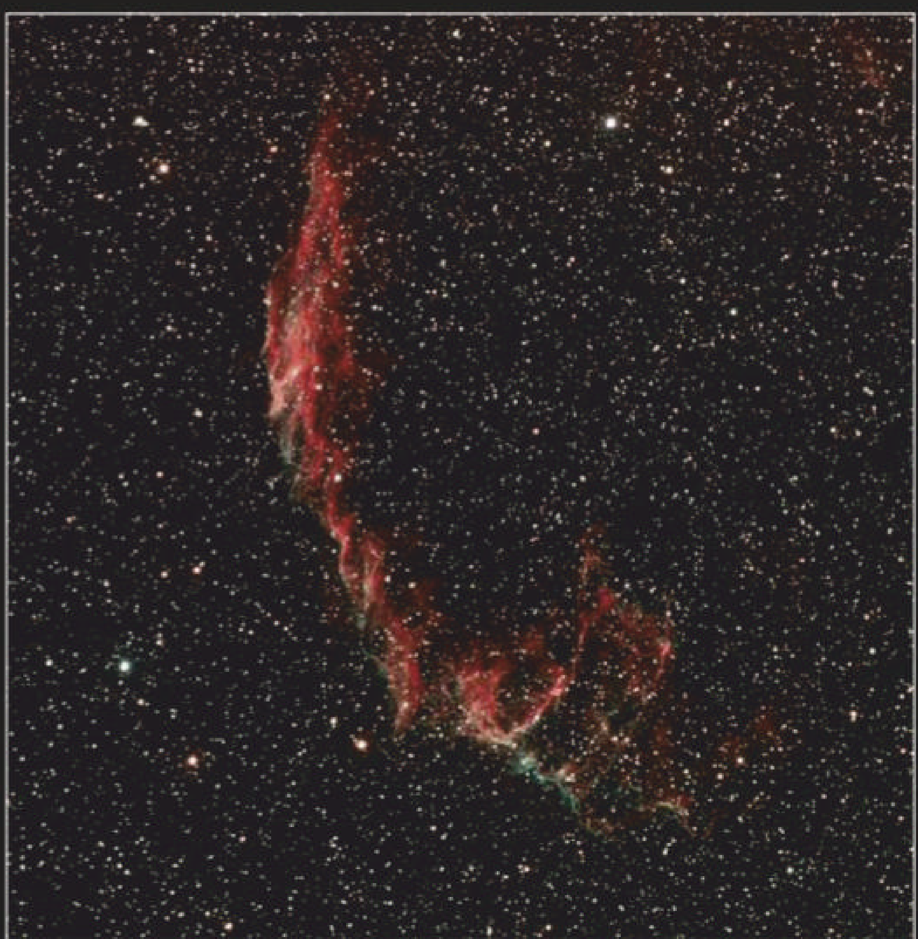
The Rosette Nebula

HASSAN ABDOLLAHABADI, NEYSHABUR, IRAN, 5, 11 OCTOBER 2018



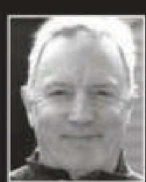
Hassan says: "To capture the nebula I had to travel to a location far away from light pollution. My only problem was the weakness of the EQ5 because each frame was close to 15 minutes, but I'm glad I was able to do it."

Equipment: ZWO ASI1600MMC camera, ZWO AS1294MC camera, William Optics Star 71mm apo refractor, Sky-Watcher EQ5 Pro SynScan mount **Exposure:** 6h **Software:** Sequence Generator, DeepSkyStacker, PHD Guiding, Photoshop



The Eastern Veil Nebula

ASHLEY NEWTON, CHELMSFORD, 2 OCTOBER 2018



Ashley says: "This was my first attempt at guiding; I wanted to compare it to my previous unguided images of the nebula. This was the first image I had done since my friend and mentor David Fountain passed away, so is dedicated to him."

Equipment: Canon EOS 60Da DSLR camera, Altair Wave Series 102mm f/7 Super ED triplet apo refractor, Eagle Core guider **Exposure:** ISO 1600, 20x3′ **Software:** Astro Pixel Processor, Lightroom

◀ The Moon

DEREK MYATT, STOKE ON TRENT, 18 AUGUST 2018

Derek says: "Having taken many lunar pictures at night with a good degree of success, I wondered if I could capture the same amount of shadow detail in a daylight image. As you can see the amount of detail is very good and this is one of my best lunar images to date."

Equipment: ZWO ASI 174 MC cooled camera, Sky-Watcher Esprit 120 ED apo refractor, Sky-Watcher NEQ6 Pro SynScan mount **Exposure:** 20x0.02" **Software:** SharpCap, RegiStax, Photoshop

▲ The Orion Nebula

PANAGIOTIS ANDREOU, EXMOOR, 10 NOVEMBER 2018

Panagiotis says: "I imaged this from the truly dark skies of Europe's first International Dark Sky Reserve. All the photons from stars and distant deep-sky objects caught my interest when I was really young, and now, more than two decades later, I can enjoy them in all their glory through my photographs."

Equipment: Nikon D810A DSLR camera, Takahashi FS-60CB refractor, iOptron CEM25EC Go-To mount **Exposure:** ISO 1,600, 9 x 180" subs, 1 X 120" sub **Software:** PixInsight, Photoshop

ENTER TO WIN A PRIZE!

ALTAIR ASTRO We've teamed up with Altair Astro UK to offer the winner of next month's Hotshots an Altair Astro Premium 1.25-inch CLS-CCD Filter with UV/IR Block & AR Coating, designed to reduce the effects of light pollution and skyglow for DSLR, CCD or CMOS cameras – www.altairastro.com • 01263 731505

Submit your pictures via www.skyatnightmagazine.com/astrophotography/gallery or email hotshots@skyatnightmagazine.com. T&Cs: www.immediate.co.uk/terms-and-conditions

2019 THE YEAR IN SPACE

Will Gater looks at the space missions and scientific endeavours that will dominate the coming year in astronomy

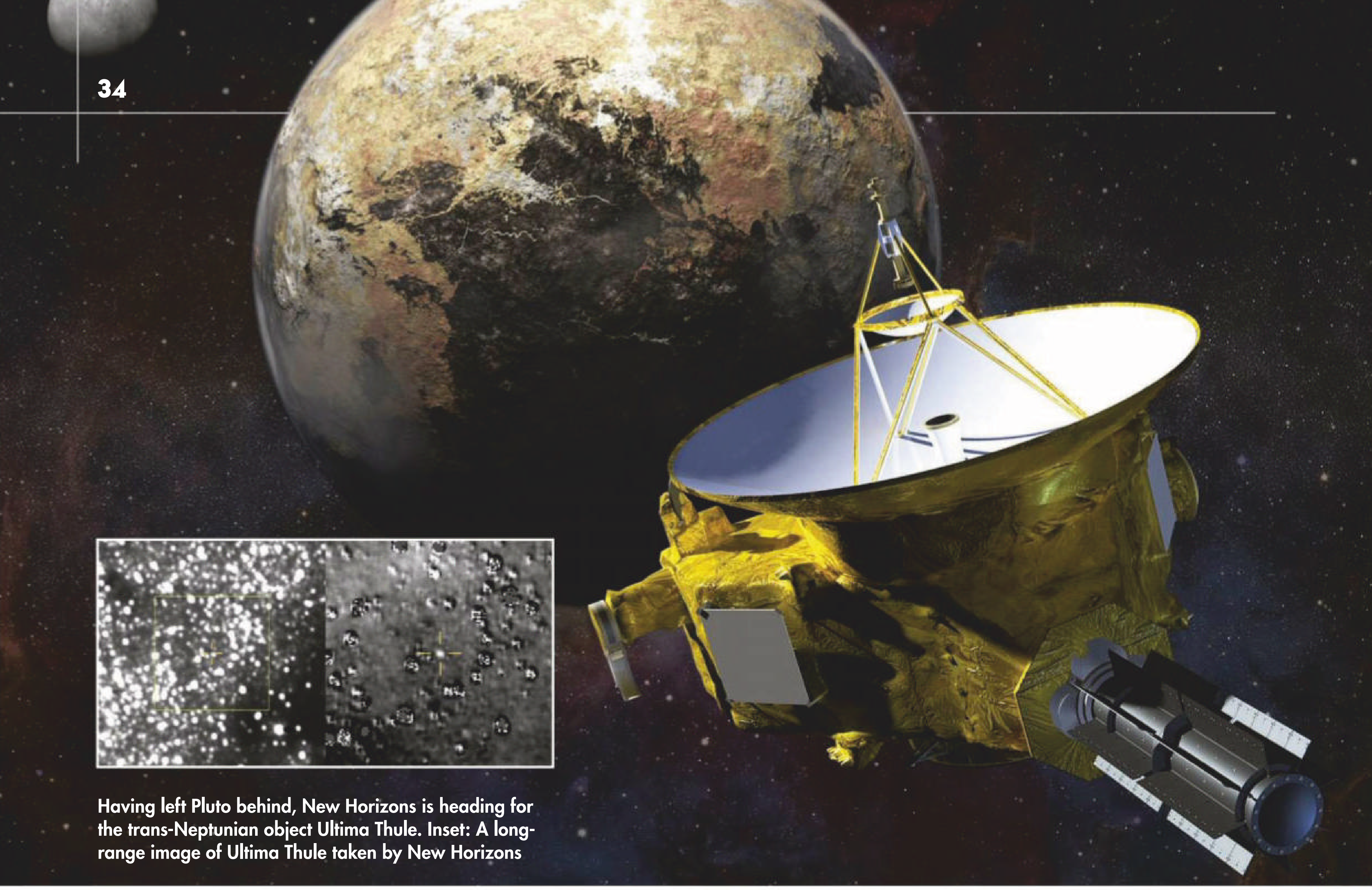
A year might be a fleeting moment in cosmic terms, but 2018 had it all when it came to astronomical advances, dramatic space launches and awe-inspiring revelations about the Universe. There was the spectacular first flight of SpaceX's Falcon Heavy rocket, captivating results from the Gaia satellite, daring asteroid landings and the beginnings of an array of new space missions destined to study everything from Mercury to the Sun and even far-off alien worlds.

If you thought this exhilarating pace was going to slacken off in 2019, you're very much mistaken. In fact, as the UK wakes up bleary-eyed on New Year's Day, out in the distant reaches of the Solar System one of the year's most anticipated events will be well underway: on 1 January NASA's New Horizons probe will make a historic flyby of one of the numerous frozen objects in the Kuiper Belt, a vast swathe of icy bodies scattered across space beyond the planet Neptune. The object – officially catalogued as '2014 MU69' but nicknamed 'Ultima Thule' by the NASA team – will be the farthest body that a man-made object has ever visited and promises to offer a window into the early Solar System and the conditions that formed the planets we know today.

Much of the excitement from this flyby comes from the unknown; and if New Horizons' swoop past Pluto in ▸

BOEING.COM

Private companies are preparing to launch space taxiing services – Boeing's Starliner will be making crewed test flights in 2019



Having left Pluto behind, New Horizons is heading for the trans-Neptunian object Ultima Thule. Inset: A long-range image of Ultima Thule taken by New Horizons

▸ July 2015 is anything to go by, there should be some thrilling moments when data and images from the probe reach Earth. For example, it's not known for certain what shape Ultima Thule is – there's a chance it could even be a binary object comprising two separate bodies. Then there's the surface itself, which New Horizon's cameras will image at high-resolution; the spacecraft's instruments should tell us what it's made of, something that could hold important clues for understanding the history of our planetary neighbourhood.

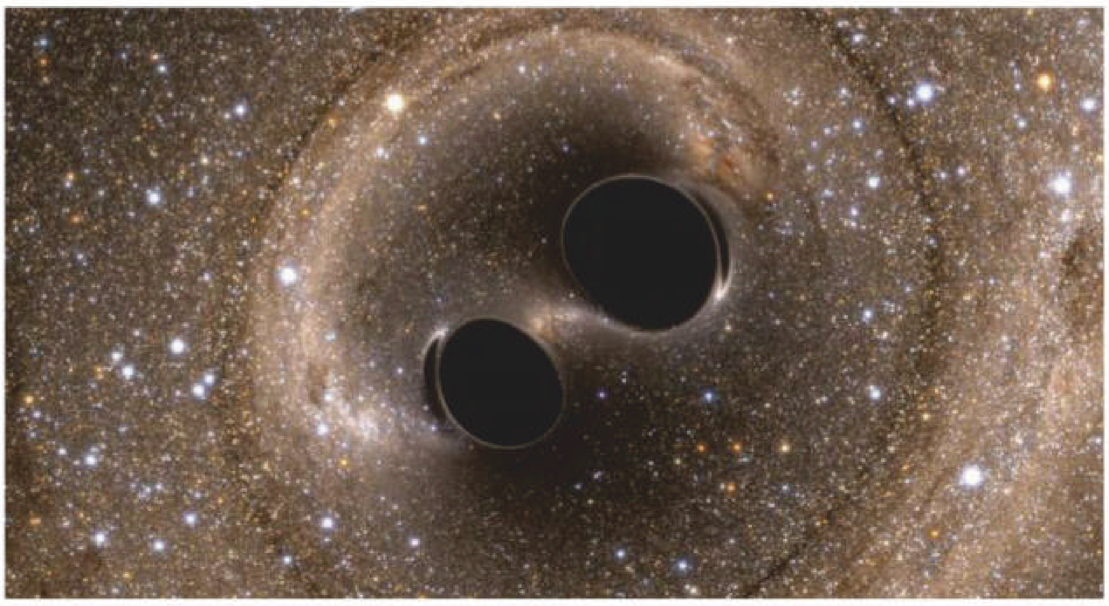
While the Kuiper Belt might seem far distant from Earth, it's right on our doorstep compared to some of the objects studied by the LIGO (Laser Interferometer Gravitational-Wave Observatory) and Virgo interferometers in the US and Europe. Gravitational waves are ripples in the fabric of space-time that can be produced by, among other things, cataclysmic phenomena such as the merging of neutron stars or black hole pairs. These cosmic ripples can travel immense distances across the Universe and their study is one of the most rapidly developing areas of astronomical research. In 2017 the field took a major leap forward when scientists detected gravitational waves from an 130 million year-old event – two neutron stars fusing – and so had enough time to alert astronomers, who then observed the event visually.

Professional astronomers had been alerted to look for the new glowing object by a private notification sent out by the researchers who had initially detected the gravitational ripples from the event. In 2019 the LIGO-Virgo teams will be making these alerts public so that astronomers everywhere – including dedicated amateurs with suitable optical and imaging equipment – can help make follow-up searches and observations of light sources associated with these enigmatic gravitational phenomena. If you'd like to find out more about the LIGO-Virgo 'Open Public Alerts' visit the LIGO webpage at **www.ligo.org/scientists/GWEMalerts.php**.

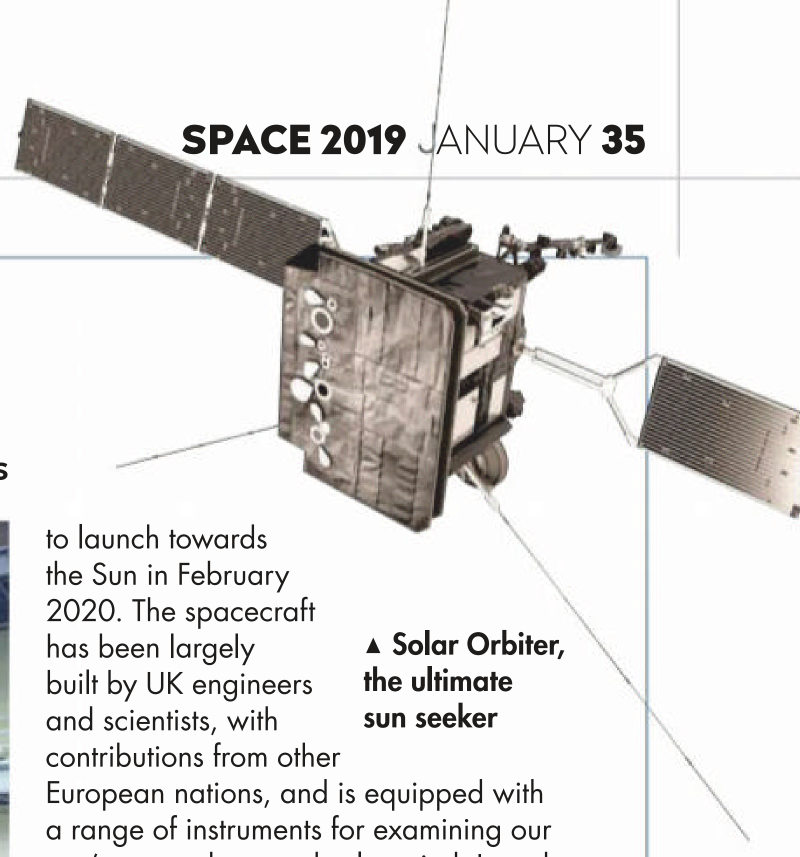
Private enterprise takes off

Closer to home there's one area of space exploration that's set to see a great deal of activity in 2019 and that's the work of various private companies developing vehicles capable of transporting astronauts into orbit. In particular, two firms – SpaceX and Boeing – have constructed spacecraft designed to ferry astronauts to the International Space Station from Florida, under the auspices of NASA's Commercial Crew Program. SpaceX's Crew Dragon capsule is scheduled to undergo its first test

▼ LIGO will be looking for evidence of gravitational waves caused by such events as neutron stars or black holes colliding



ESA, NASA X2, THE SXS (SIMULATING EXTREME SPACETIMES) PROJECT, NASA/JHUAPL/SWRI, GETTY IMAGES



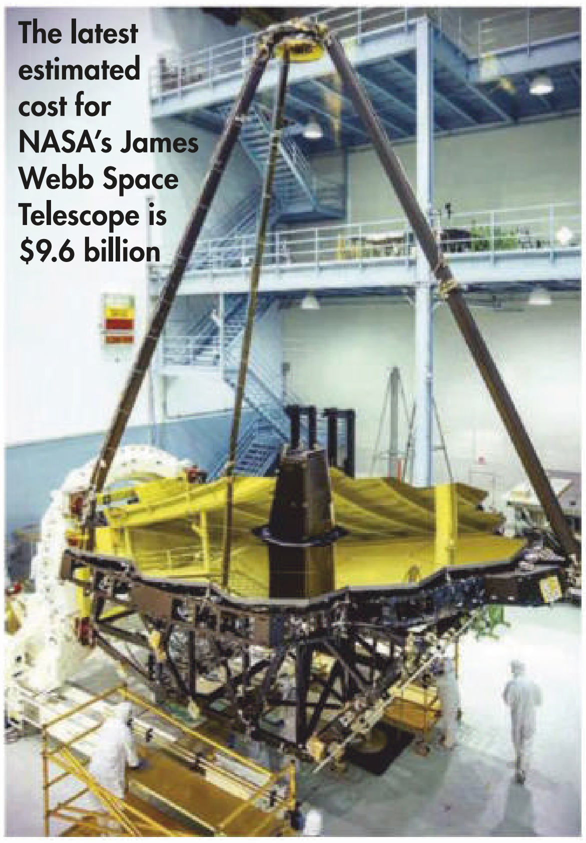
ON THE HORIZON

Missions set to launch, or do their most important work, in the coming years

While 2019 sees many space projects doing great work, there are plenty of others getting ready for their big moment in the years to come. The most famous of these – and the one that's been beset by numerous delays and controversies – is NASA's James Webb Space Telescope (JWST). The agency announced in June last year that the orbiting infrared observatory – with a huge 6.5m-wide segmented mirror – will have its launch pushed back once again to late March 2021. But many astronomers are willing to wait, given the potential for truly ground-breaking science from the telescope. By observing at infrared wavelengths, the JWST will be able to peer much farther back in time than even the venerable Hubble. It should also revolutionise exoplanet science and give researchers clues about other important eras of the Universe, like when the first stars lit up their surroundings.

Another mission being readied for lift-off in the next few years is ESA's Solar Orbiter, due to launch towards the Sun in February 2020. The spacecraft has been largely built by UK engineers and scientists, with contributions from other European nations, and is equipped with a range of instruments for examining our star's atmosphere and solar wind. In order to make its observations, the probe will position itself in an elliptical orbit that will see it – at times – looping around the Sun within the orbit of Mercury, so it will be equipped with a heat shield to protect its electronics from the high temperatures.

Looking further into the future, there's also the 2021 launch of ESA's Euclid mission, which will study the enigmatic phenomena 'dark energy' and 'dark matter' by accurately measuring the acceleration of the universe. So space fans can be guaranteed of a brimming schedule for many years to come.



The latest estimated cost for NASA's James Webb Space Telescope is $9.6 billion

▲ **Solar Orbiter, the ultimate sun seeker**

flight – without astronauts inside – on a Falcon 9 rocket in January. That'll be followed by a crewed launch, which is scheduled for sometime in June.

Similarly, Boeing has an uncrewed test of its Starliner spacecraft scheduled for March and another flight, with astronauts on board, pencilled in for August. All eyes will be on these tests as many in the US are hoping they will herald the moment when the country regains its ability to regularly launch astronauts from home turf – something it hasn't been able to do for nearly eight years, following the retirement of the Space Shuttle.

One destination future commercial space missions may go to is our nearest neighbour, the Moon. In 2019 both the Chinese and Indian space agencies intend to send robotic missions to the Moon. In fact, at the time of writing the Chinese also have a lunar lander – Chang'e 4 – preparing for a launch in December 2018. The mission intends to touch down on the lunar far side, making it the first spacecraft to do so, and it will explore the South Pole-Aitken basin area with a 1.5m-long rover.

That mission will be followed in 2019 by Chang'e 5, which will send a sample-return probe to the lunar surface near Mons Rümker in the northwest of the nearside. Meanwhile the Indian Space Research Organisation (ISRO) is set to launch its Chandrayaan-2 lunar mission at the beginning of the year; it consists of a lander and rover as well as an orbiting lunar satellite. As with China's Chang'e-4, the destination for the Chandrayaan-2 lander will be the Moon's southern polar region.

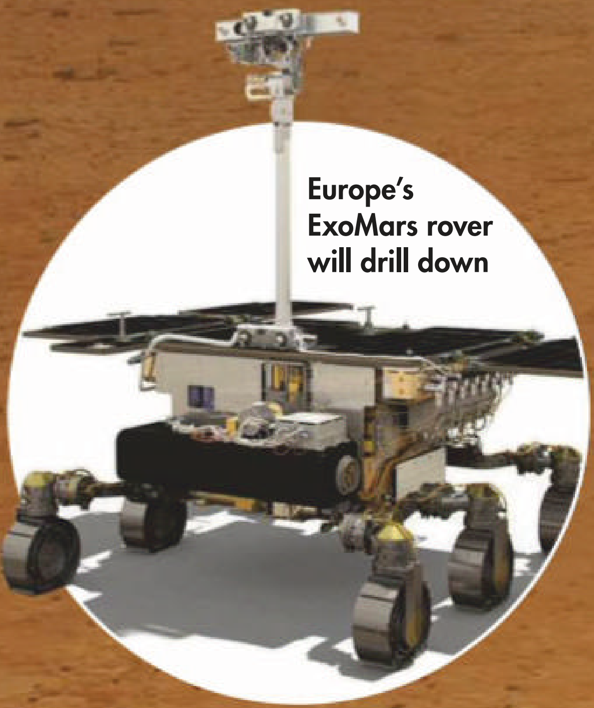
Beyond the Moon, the asteroid belt will be another region of focus for robotic explorers in 2019. Both NASA and the Japanese Space Agency, JAXA, have spacecraft exploring asteroids this year. JAXA's Hayabusa2 mission has already reached its target, a 900m-wide asteroid named 'Ryugu'. In autumn ▸

► **SpaceX's Dragon capsule is set for a year of testing throughout 2019**

India is set to send Chandrayaan-2 to the Moon

ONWARDS, TO MARS!

Could 2021 mark the year we find out if Mars was ever habitable?



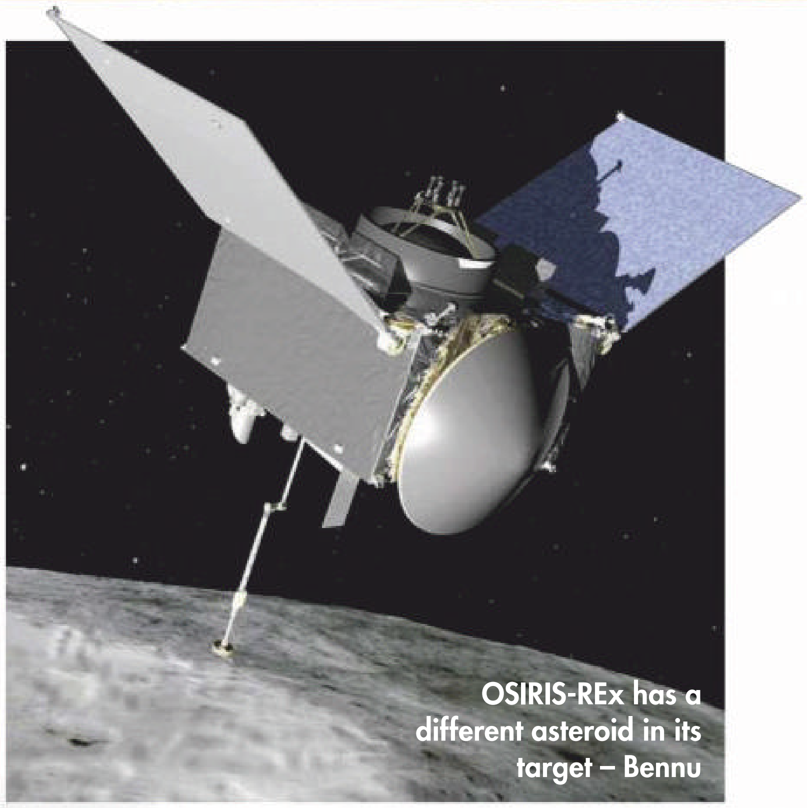
Europe's ExoMars rover will drill down

The tail end of 2020 is going to be all about Mars, it seems, as not one, but two new rovers set out for the Red Planet, both aiming to land in 2021. They'll join NASA's Curiosity Rover and InSight lander on the surface as well as Opportunity, whose fate – at the time of writing – is uncertain following a Martian dust storm that appears to have had a nasty effect on its circuits.

NASA's Mars 2020 rover is being built along the lines of Curiosity – and outwardly looks very similar – but has a more advanced collection of instruments and cameras. It'll use the same rocket-powered skycrane system as Curiosity to safely get down to the surface when it lands on Mars in February 2021. Once there it will wander across the Martian soil looking for indications of past life on the planet. The rover will traverse the Red Planet, collecting and storing samples for return to Earth by a future – as yet unconfirmed – mission.

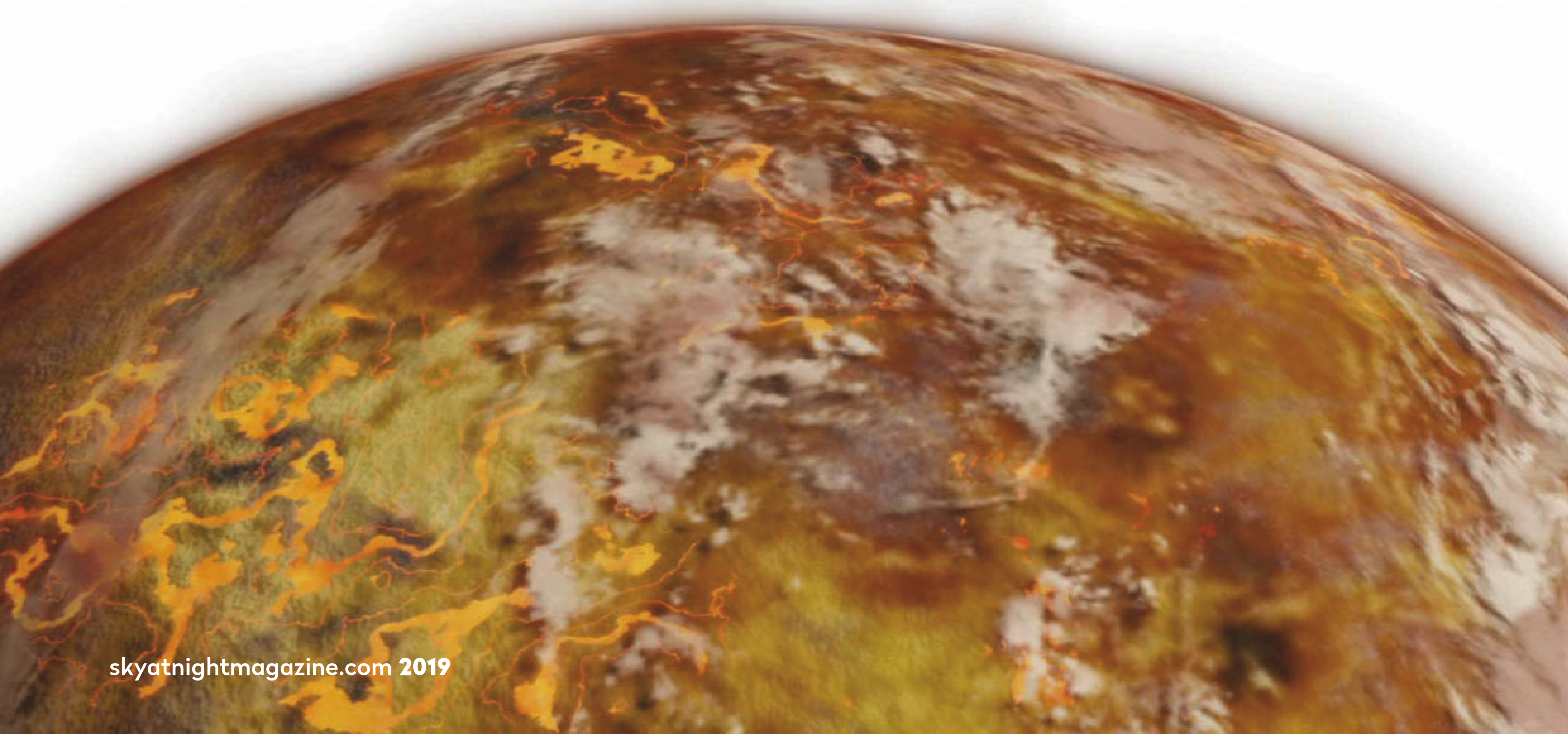
Europe meanwhile will also be heading to Mars in 2020 with its own ExoMars rover. It will be equipped with a large drill that will allow it to take samples from the soil below Mars's harsh surface environment. It will then analyse that material with its on-board instruments; it'll be looking for clues about whether Mars has, or once had, life on it.

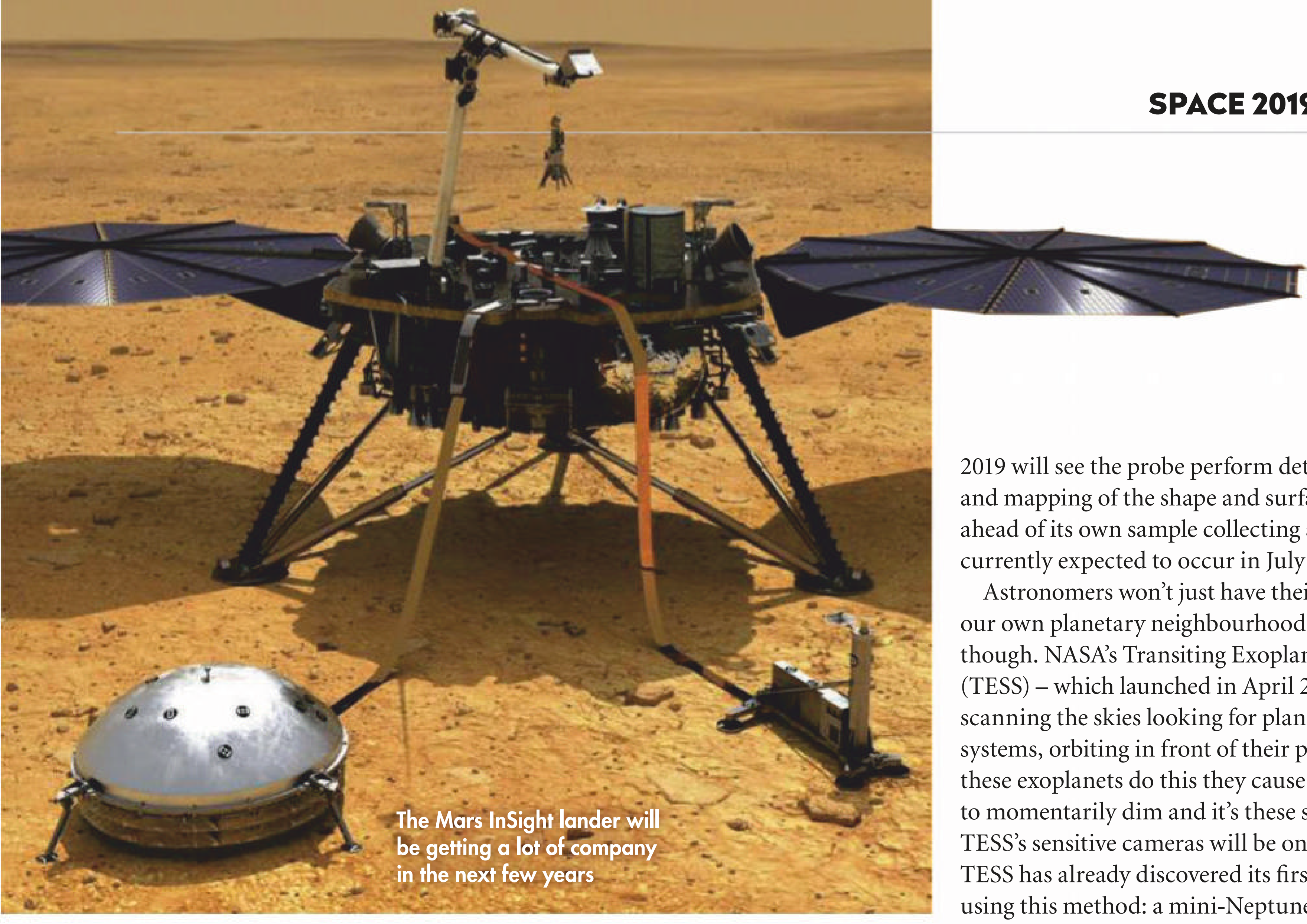
Hayabusa2 will be sending back more data from Ryugu in 2019



OSIRIS-REx has a different asteroid in its target – Bennu

ESA, NASA X4, FLICKR.COM SPACEX, ISTOCK





The Mars InSight lander will be getting a lot of company in the next few years

▸ 2018 it deployed several hopping probes to the surface of the asteroid including two 'MINERVA-II-1' landers, developed by JAXA and the University of Aizu, and the box-shaped MASCOT lander, built by CNES in France and DLR in Germany.

All of the landers were successful and returned extraordinary images showing fine details in the rocks that litter the surface landscape. The main Hayabusa2 spacecraft has been returning spectacular images of Ryugu of its own and in 2019 will jettison an 'impactor' toward the asteroid's surface. The spacecraft will then approach the crater formed by the impactor and attempt to collect a sample of exposed subsurface material. If all goes to plan, it's hoped Hayabusa2 will deliver the precious cargo to Earth in late 2020.

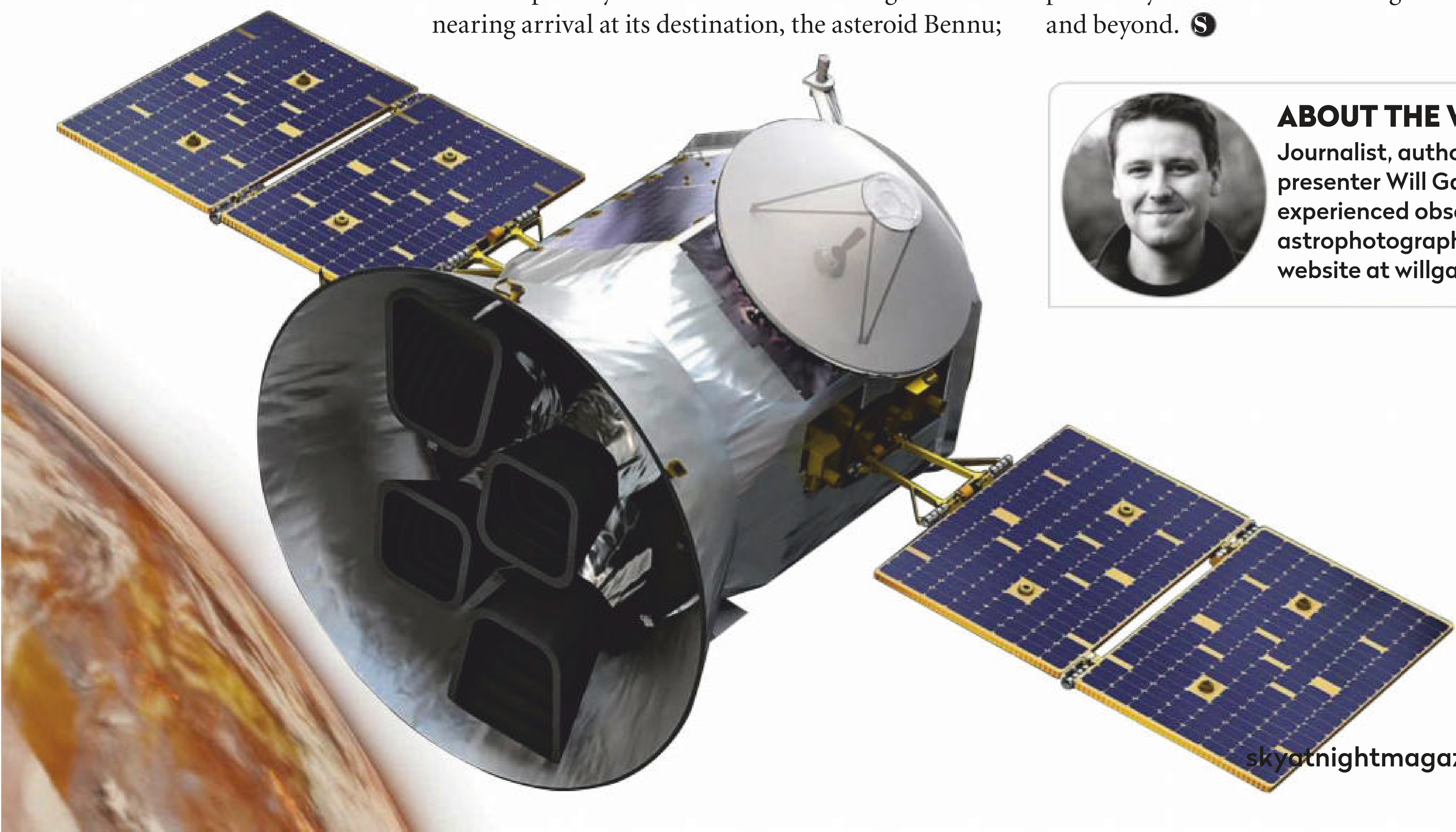
NASA's OSIRIS-REx mission also has a sample-return capability and at the time of writing it is nearing arrival at its destination, the asteroid Bennu; 2019 will see the probe perform detailed photography and mapping of the shape and surface of Bennu ahead of its own sample collecting attempt, which is currently expected to occur in July of 2020.

Astronomers won't just have their attention on our own planetary neighbourhood during 2019, though. NASA's Transiting Exoplanet Survey Satellite (TESS) – which launched in April 2018 – will be scanning the skies looking for planets in other solar systems, orbiting in front of their parent stars; when these exoplanets do this they cause their star's light to momentarily dim and it's these small dips that TESS's sensitive cameras will be on the look out for. TESS has already discovered its first extrasolar worlds using this method: a mini-Neptune-like planet orbiting a star 60 lightyears away and a scorched 'hot Earth' that rapidly circles a dwarf star 49 lightyears from us. And with the satellite set to survey 200,000 stars in its mission lifetime, it's a pretty safe bet that 2019 will see it uncover even more.

In a similar vein, ESA is expected to launch its CHEOPS (CHaracterising ExOPlanets Satellite) mission sometime this year. Like TESS it will make studies of exoplanets that 'transit' in front of their stars. By making accurate measurements of the sizes of these distant worlds with CHEOPS, astronomers hope to learn more about their fundamental properties and how they formed and evolved.

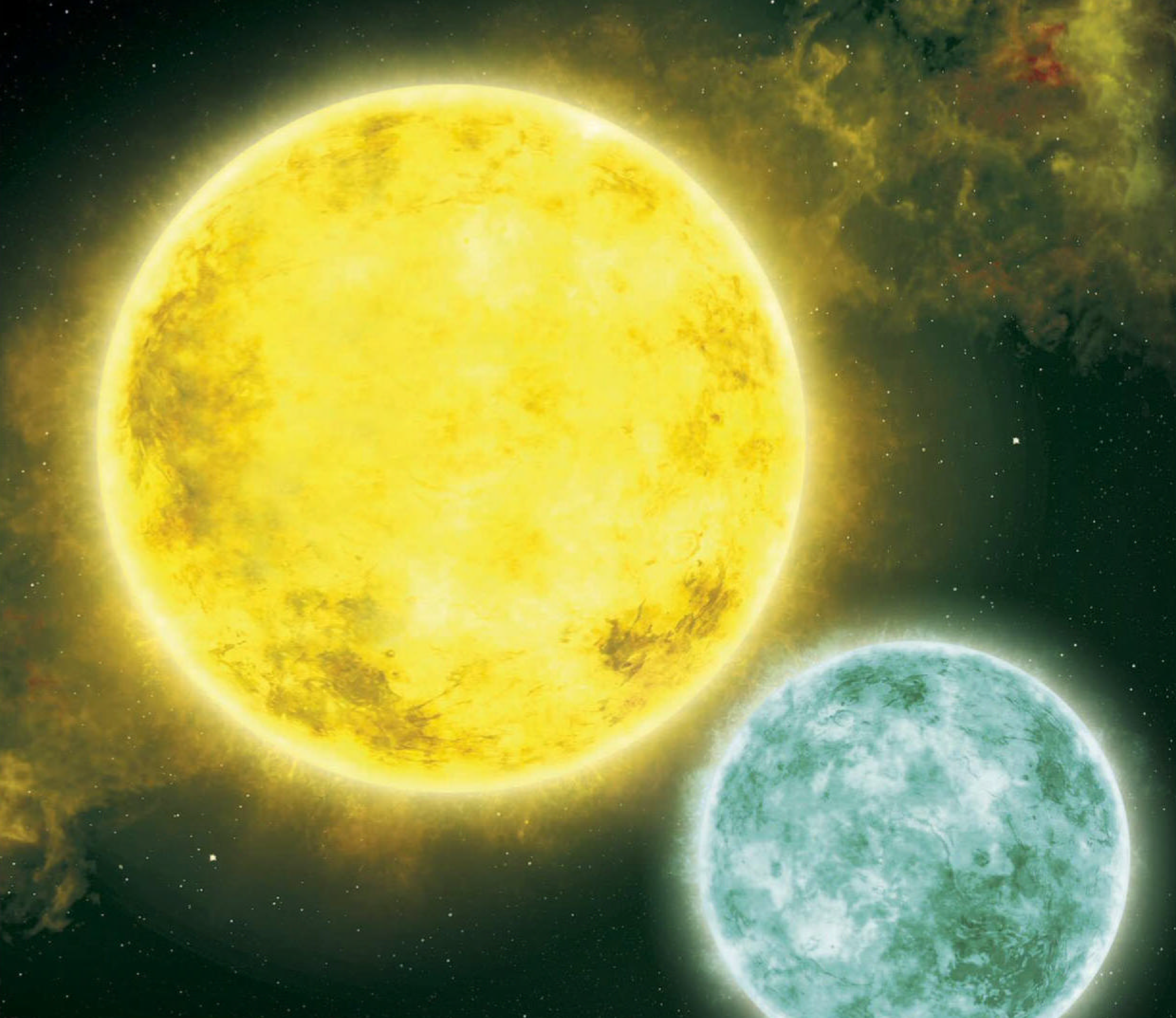
So, among the many exciting moments we have to look forward to in space this year, 2019 could very well end with us not only having found an array of new alien worlds, but also learning more about others that spark the imagination and set up the possibility of even more thrilling discoveries in 2020 and beyond.

▼ TESS will continue to scan the Universe in minute detail in 2019, looking for transits – the give-away evidence of exoplanets



ABOUT THE WRITER

Journalist, author and presenter Will Gater is an experienced observer and astrophotographer. Visit his website at willgater.com



Green-tinged stars like the one in this illustration don't actually exist – they are often the result of colour-contrasting double stars. But they remain a fun observing challenge to hunt down

ABOUT THE WRITER

Phyllis Lang is a writer, telescope-maker and owner of the astronomy software company Knightware

Getting the GREEN LIGHT

A small handful of stars appear to glow emerald in the night sky. Astronomer **Phyllis Lang** reveals how to spot them

For many years I've observed all kinds of deep-sky objects. I have been most interested in planetary nebulae, partly because they're most likely to show colour. Within the last few years I've also become interested in the colours of stars, particularly colour-contrasting double stars. A long-time observing friend of mine brought up the idea of observing green stars, and a social observing project began.

Stars seem to appear in almost every colour of the rainbow. As described in Star of the Month in our May issue, both eye physiology and the spectrum play a part. The novice observer may detect no colour in stars but, in fact, any star has an apparent colour that is detectable with photometry. The star's light can be filtered so that separate colour components (wavelengths) can have their brightness measured. The brightness of a star's light also determines whether the human eye can detect a colour. If a star's light isn't bright enough to stimulate the eye's cones, we see no colour. The rods in the eye are more sensitive to light, but only detect shades of gray. Thus, a bright star may appear to have colour, while a dimmer star may appear only whitish or greyish.

Bright stars may appear red, orange, yellow, blue or white. Noticeably absent from this palette is green, even though the human eye is most sensitive to green light. Instead, a pair of double stars with different-coloured components interact in such a way they may give the impression that one of the stars is green or bluish green. This small handful of 'green' stars are worth seeking out and make for a fun observing challenge.

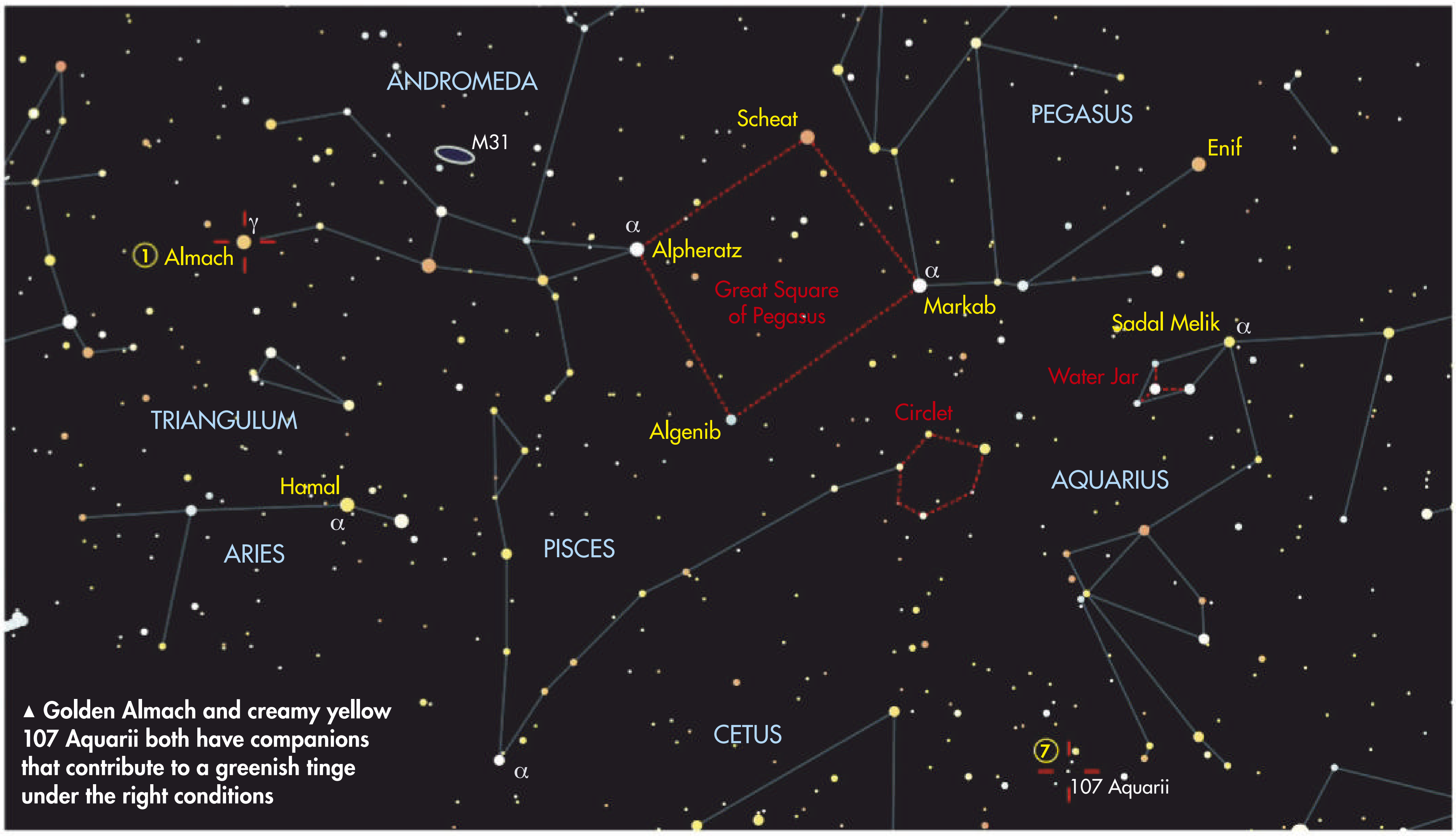
Observations in this feature were made with an 8-inch reflector and rather clean eyepieces. Visual impressions at different magnifications are included. Many of the stars on our list are bright so they can be examined successfully with binoculars or small telescopes, but colour may be difficult to tease out without higher magnification and moderate aperture. A steady mount is required for binoculars and steady seeing is a must.

Your results may not match those of another observer, but it is an enjoyable exercise to compare results with your observing companions. Don't be surprised if there is great debate among participants! You may find that telescope aperture, magnification, local light pollution and age of the eye affect your findings. Also, your first impression of colour may be a green hue, but the longer you look at a star, the less green and more blue or yellow it might appear. Any of these results should be noted among your observations. ▸

YOUR BONUS CONTENT

Download Deep-Sky Planner, Argo Navis and SkySafari files to help your automated telescope find Phyllis's green stars.

ISTOCK

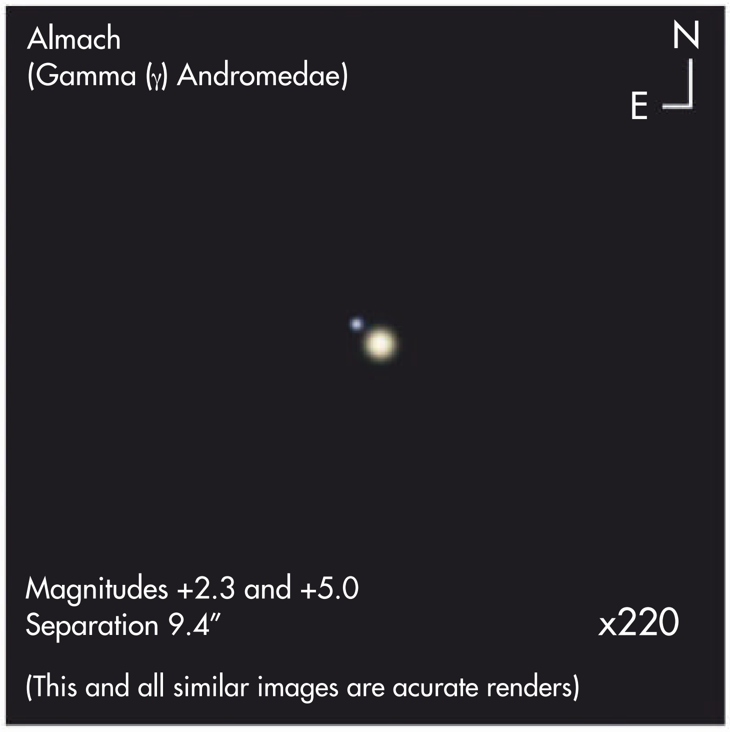


▲ Golden Almach and creamy yellow 107 Aquarii both have companions that contribute to a greenish tinge under the right conditions

1 Almach (Gamma (γ) Andromedae)

Although a close pair separated by 9.4 arcseconds, Almach is not difficult to split. It is the third in a line of bright stars extending eastward from Alpheratz (Alpha (α) Andromedae) in the northeastern corner of the Great Square of Pegasus. From mag. +2.0 Alpheratz, move 7° northeast to mag. +3.3 Delta (δ) Andromedae, then a further 8° northeast to mag. +2.0 Mirach. Finally, move 12.5° northeast to find Almach.

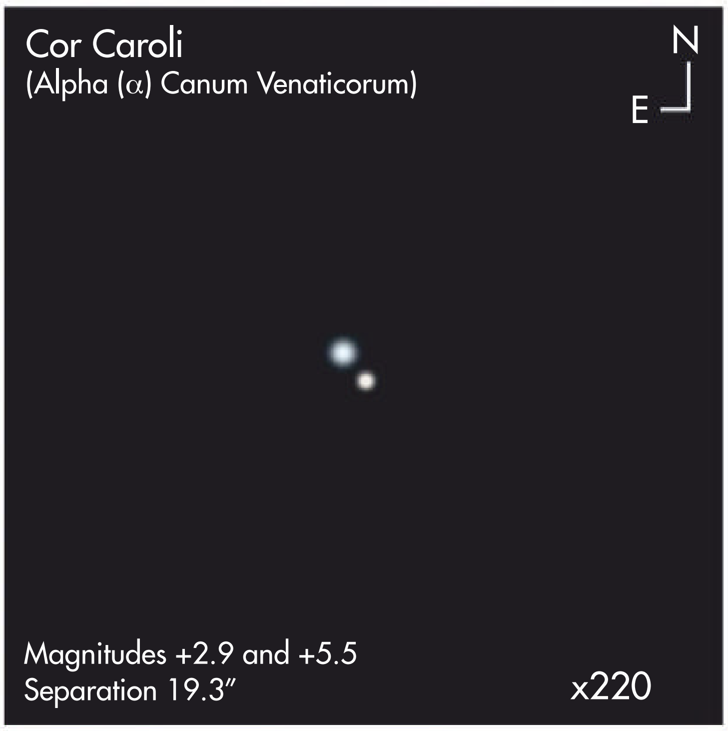
The brighter A component is spectral class K3 that appears gold at 63x magnification. The fainter B companion – noticeably dimmer at mag. +4.8 – is actually a triple star system in itself. With all three components in such close apparent proximity to each other (under 0.2 arcseconds) they appear as one blue star to all but the very highest specification amateur equipment. Two of these components are type-B main sequence stars orbiting each other. The other is a type A0 star, which may possibly be the reason they merge to take on a greenish hue at 200x.



2 Cor Caroli (Alpha (α) Canum Venaticorum)

A radiant pair with 19.3 arcseconds of separation, Cor Caroli makes for an easy split at lower powers. The brightest point of light in the constellation of Canes Venatici, the Hunting Dogs, Cor Caroli (the name means 'Charles's heart') is easy to spot – it's the brilliant star 10° south and 10° west of Eta (η) Ursa Majoris, which marks the end of the Plough's handle.

Both components are spectral type A0 but their colours are not identical. They are mag. +2.8 and mag. +5.5 respectively, so identifying the components is easy. At 62x magnification, the A component appears creamy yellow while the B component comes across as a pale yellow-green. Go to 185x magnification, though, and the B component takes on a pale blue-green tinge.



ALL PICTURES: PETE LAWRENCE

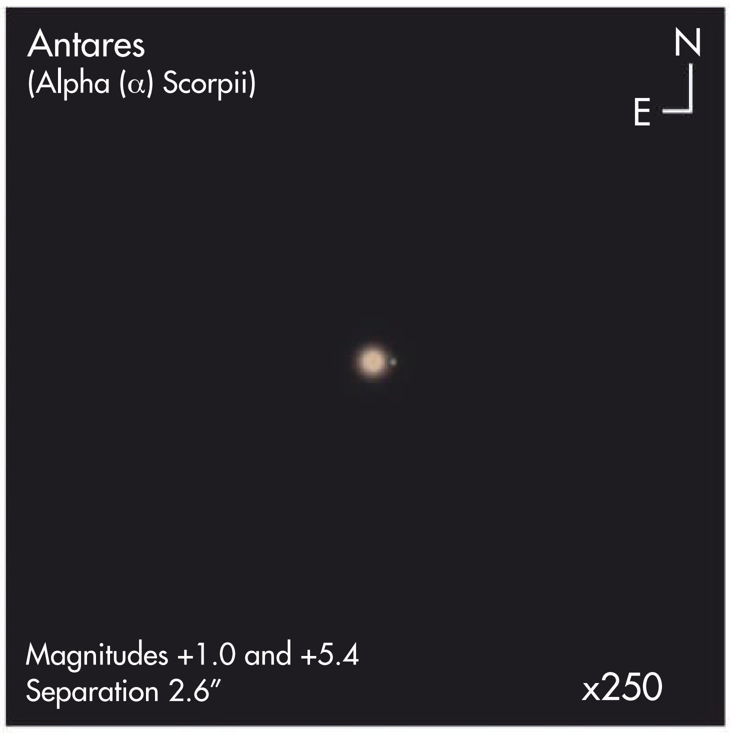
3 Acrab (Beta (β) Scorpii)

Take the opportunity to observe these stars when they are highest in the sky at your location, because while, at 13.7 arcseconds, they may be an easy pair to split, they don't rise very high in the sky at northerly latitudes.

Acrab is a B0-type star located in a star-filled region of Scorpius near the plane of our Galaxy. It is one of the brighter stars in the northernmost claw of the Scorpion. Beginning with Antares, the brightest star in the body of the Scorpion, move 7.5° northwest to mag. +2.3 Delta Scorpii. This is the middle star in a 6.5° line of mag. +2.0 stars orientated nearly north-south. Acrab is the northernmost star in this line, about 3° north-northeast of Delta Scorpii. It is actually the tip of the northern claw.

The main component is a B1 spectral class star that appears warm white at 62x magnification. The fainter component is a B2 class star that appears pale blue-green at moderate (62x) and higher powers (200x).

4 Antares (Alpha (α) Scorpii)



The most challenging pair on our list to separate visually is this bright, naked-eye star in the heart of Scorpius (as described above). It appears orange to most observers, but when examined carefully in steady skies with enough aperture, you can see that the star actually comprises two components, separated by just 2.5 arcseconds.

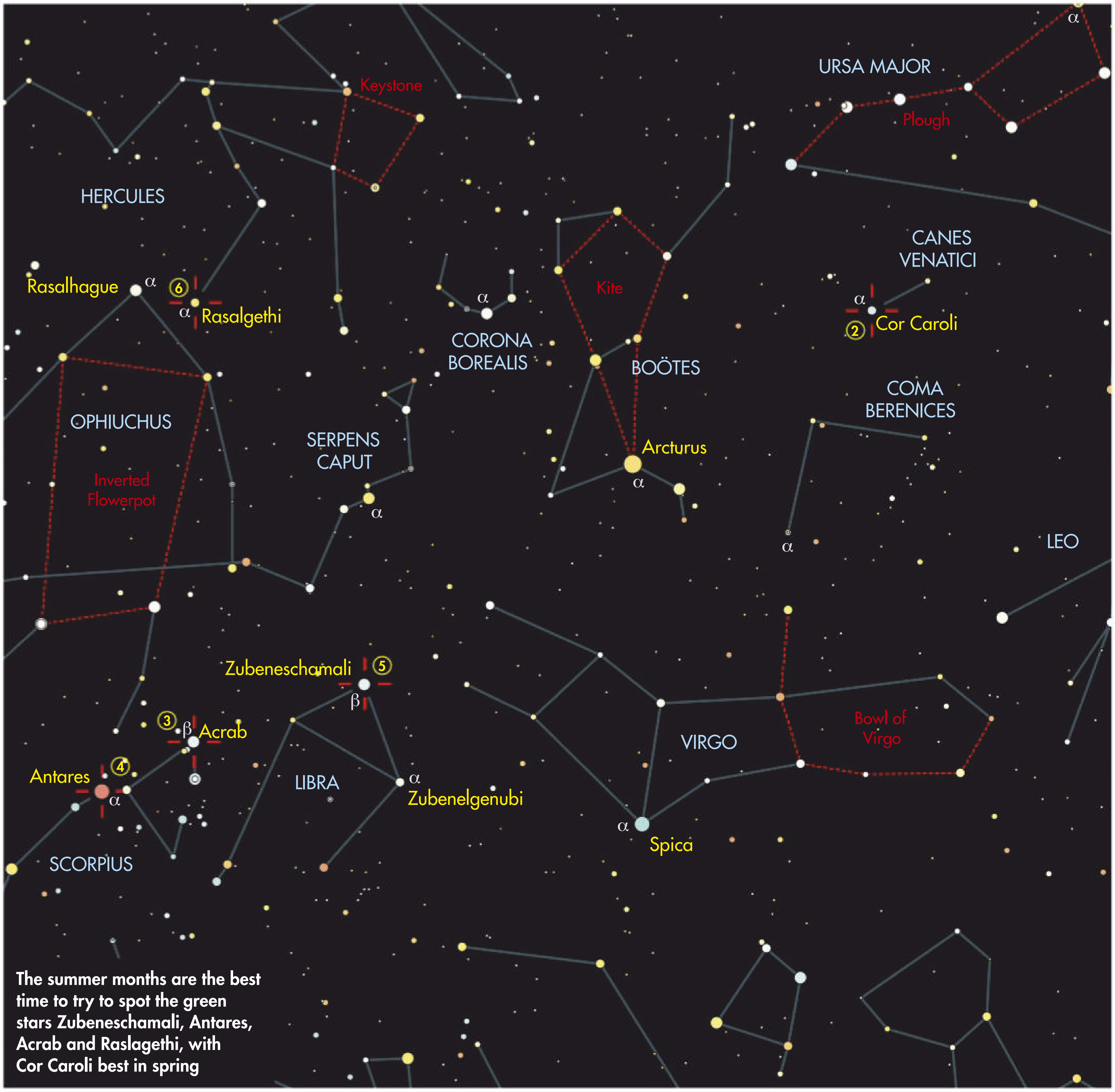
Alpha (α) Scorpii does not give up its component pair easily, and not just because of their narrow separation. The bright orange light of the 1st magnitude primary (Antares A) can easily overwhelm the neighbouring mag. +5.4 secondary (Antares B) unless the sky is quite steady during your observation.

You'll want to use at least 100x magnification to split the pair, and while Antares B is actually blueish-white in colour, it has a reputation for appearing green in contrast to the large red primary star.

Green at a glance

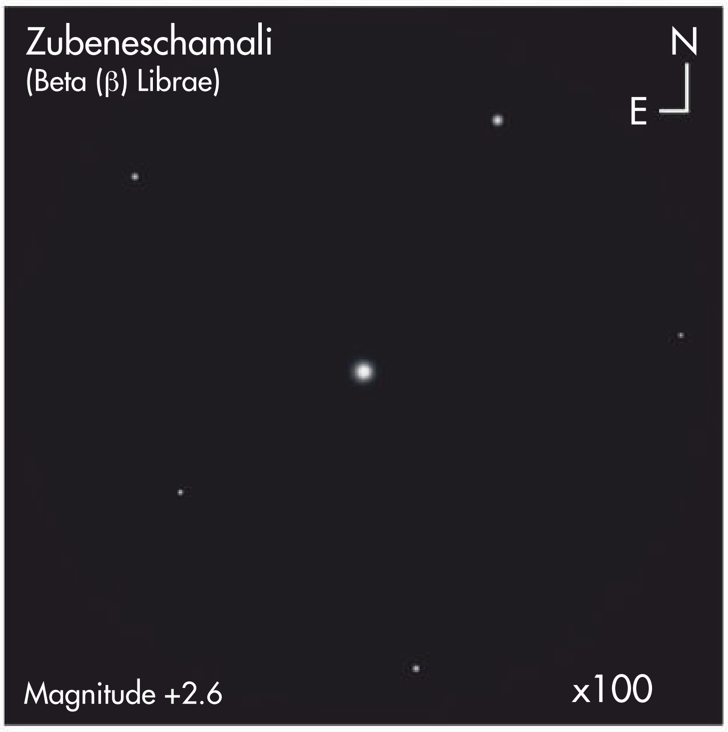
Use our table to help you complete the tour of emerald stars

Object	Constellation	Magnitudes	Separation	RA	Dec.
Gamma (γ) Andromedae	Andromeda	+2.31 and +5.02	9.4″	02h03m53.9s	+42°19'46.6"
Alpha (α) Canum Venaticorum	Canes Venatici	+2.85 and +5.52	19.3″	12h56m01.47s	+38°19'07.2"
Beta (β) Librae	Libra	+2.62	NA	15h17m00.34s	-09°22'58.7"
Beta (β) Scorpii	Scorpius	+2.59 and +4.52	13.7″	16h05m26.23s	-19°48'19.9"
Alpha (α) Scorpii	Scorpius	+0.96 and +5.4	2.5″	16h29m24.46s	-26°25'55.7"
Alpha (α) Herculis	Hercules	+3.48 and +5.4	4.64″	17h14m38.85s	+14°23'26"
107 Aquarii	Aquarius	+5.65 and +6.46	6.7″	23h46m00.92s.	-18°40'42"



The summer months are the best time to try to spot the green stars Zubeneschamali, Antares, Acrab and Raslagethi, with Cor Caroli best in spring

5 Zubeneschamali (Beta (β) Librae)



This is the only singleton star in our list. Our other candidates are components in a binary or multiple star system, and it is the juxtaposition of colours that leads to a suggestion of a green tint. But Zubeneschamali manages to take on a green hue all on its own.

Libra is not the easiest constellation to spot in skies that suffer any light pollution. Perhaps the easiest place to start is bright Spica (Alpha (α) Virginis). From Spica, move 27.5° east and north by 1.5°. Zubeneschamali is the second brightest star in Libra, so it should be evident even at a low power.

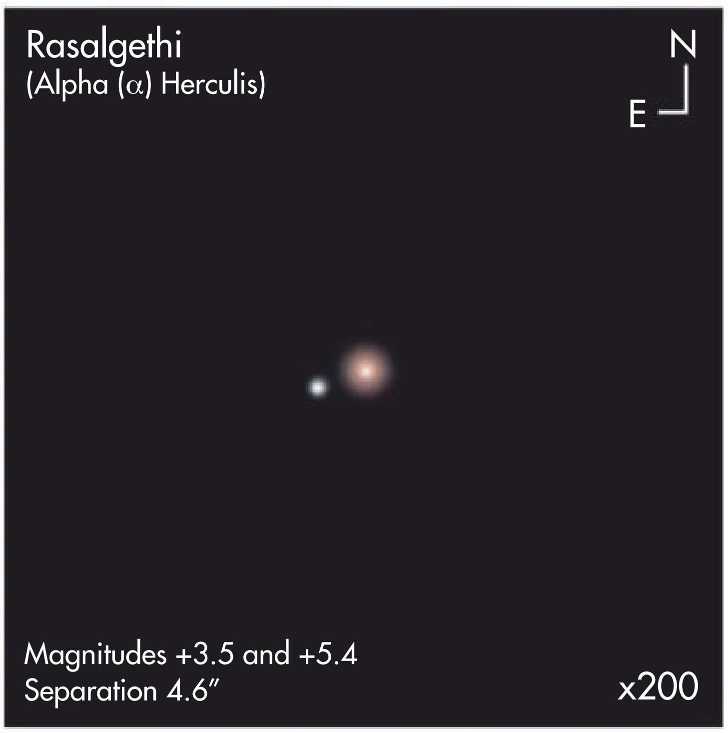
Beta (β) Librae is a spectral class B8 star that appears pale blue or blue-green at 62x magnification. At 110x it may appear pale green. Step away from the eyepiece for a moment then return, and note your initial impression of the star's colour. It is this technique that may produce the most convincing impression of green.

ALL PICTURES: PETE LAWRENCE

6 Rasalgethi (Alpha (α) Herculis)

This is another easy pair to see with small telescopes, although tricky to split at only 4.6 arcseconds' separation. Rasalgethi is the southernmost star in the eastern leg of Hercules. Find mag. +3.9 Epsilon (ε) Herculis at the southeastern corner of the Keystone of Hercules. Next, proceed 7° southeast to 3.1 magnitude Delta (δ) Herculis, the eastern knee. From Delta, move 10.5° south to mag. +3.3 Alpha (α) Herculis.

Moderate to good seeing will be required to split the components and discern their colours. Again, both components are the same spectral class (M5), but they appear to be different colours at the eyepiece. The brighter mag. +3.5 A component appears orange at 62x magnification while the dimmer mag. +5.4 B component appears green or yellowish green at 110x.

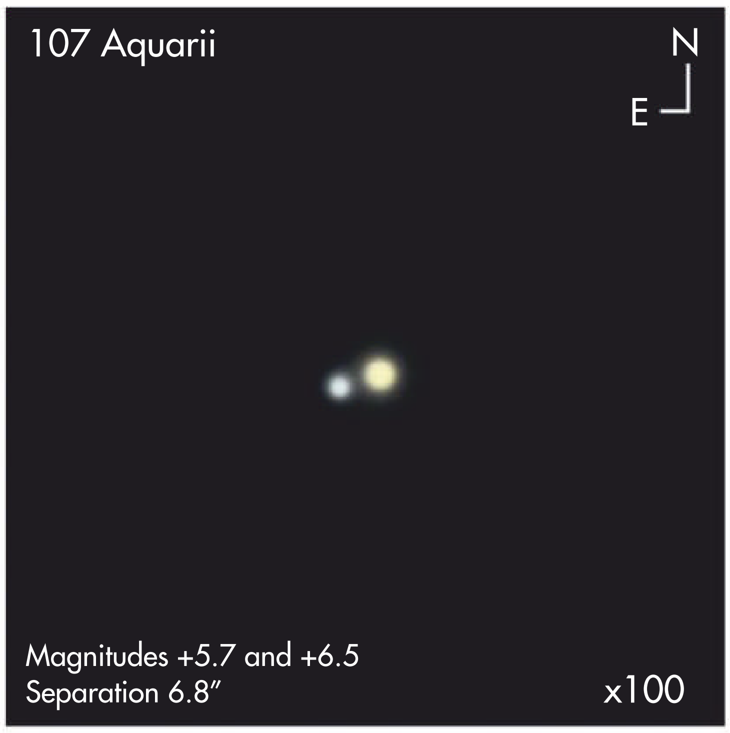


7 107 Aquarii

The two stars that comprise 107 Aquarii are the dimmest duo on our list. But while faint, this dual object is not particularly difficult to find, and is even naked-eye visible in dark skies under good seeing conditions. You'll need some powerful magnification to spot any hints of green, though.

While located in the region of the sky occupied by Aquarius, the Water Bearer, 107 Aquarii is not actually a part of the constellation, so some star-hopping is required to pin it down. First, look for mag. +2.1 Diphda (Beta (β) Ceti) in the constellation of Cetus, the Whale. 107 Aquarii lies 13.7° to the west of that. Find a pair of stars that are similar in brightness (mag. +5.6 and mag. +6.5) and separated by just under seven arcseconds.

At lower power, the stars are noticeably different in colour and magnitude, but higher power is needed to tease out any real colour. The primary is an A9 spectral class star appearing pale creamy yellow at 200x magnification; the B component is type F2 and reveals slightly pale blue tone at 200x. To spot the greenish tint you may need to observe the star at high altitude in a steady sky with higher magnification. S



A guide to stellar spectra

Stars shine in various hues. Here's a guide to the different types of stars, their temperature, structure and colour

Spectral	Colour	Temperature (K)*	Special Features
O		28,000-50,000	Ionised helium
B		10,000-28,000	Helium, some hydrogen
A		7,500-10,000	Strong hydrogen, some ionised metals **
F		6,000-7,500	Hydrogen and ionised metals such as calcium and iron
G		5,000-6,000	Both metals and ionised metals, especially ionised calcium
K		3,500-5,000	Metals
M		2,000-3,500	Strong titanium oxide and some calcium

* To convert approximately to Fahrenheit, multiply by 9/5. ** Astronomers regard elements heavier than helium as metals

AI at the CONTROLS

NASA is putting artificial intelligence in charge of exploring the Solar System. **Terena Bell** investigates

▲ AI will be at the forefront of NASA's Europa project to probe Jupiter's icy moon

From predicting volcanic eruptions on Earth to building a Mars rover that thinks for itself, at NASA, "Artificial Intelligence is everywhere". That's according to Steve Chien, head of artificial intelligence for the Jet Propulsion Laboratory, who can list NASA project after project that AI oversees: visiting near-Earth objects, tracking methane emissions, planning missions to other stars. Even long-term exploration mission control may not be far off.

"One of the problems with getting off into the extreme regions of the Solar System," says Chien, "is that it takes a long time to get there." New Horizons, for example, took eight years to reach Pluto. NASA has considered harpooning an extreme trajectory object in order to traverse the Solar System more quickly, but that would create a different concern: communication. Chien says these objects – such as asteroid NF23 – can move at at speeds of around 30,000 km/h and at that velocity, dialogue isn't possible. "All the control of that 10-year mission would have to be done by an AI system," he explains.

That's just one example. On the following pages, we'll share how NASA uses AI for Mars exploration, the search for life on Europa and for tracking climate change and natural disasters on Earth.

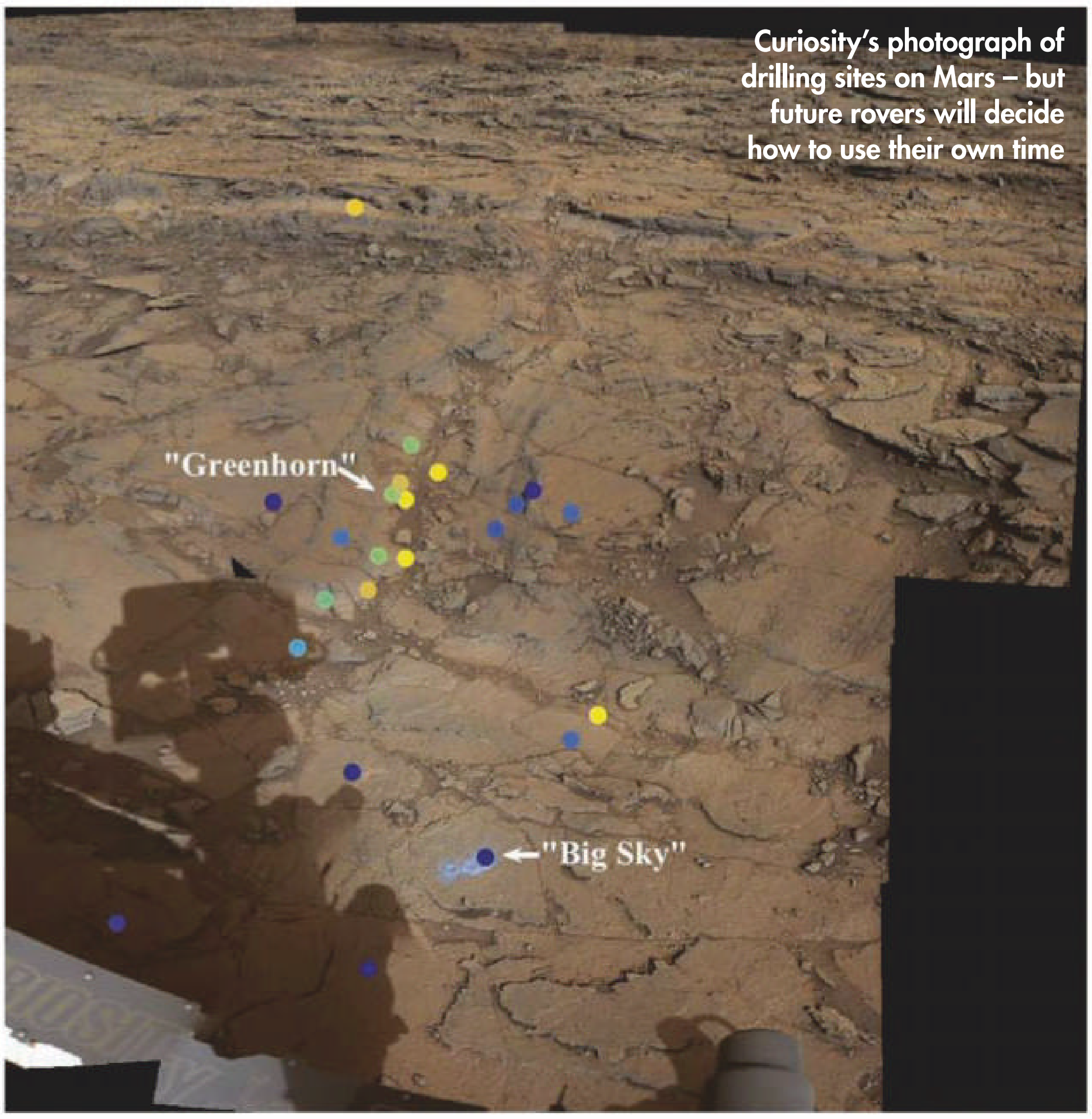
Exploring Mars

AI will soon be driving Martian rovers

Humans may not have reached Mars yet, but AI has, in the form of the targeting software currently used by the Mars Science Laboratory's Curiosity rover. Scientists, Chien explains, use artificial intelligence to specify very high-level target requests, such as searching for rocks with a set texture, size or distribution. The software then determines the right orientation for aiming NASA's Chemistry and Camera (ChemCam) laser at the targets and fires it, burning the planet's ever-present iron dust off their surfaces in order to expose their underlying mineral structures.

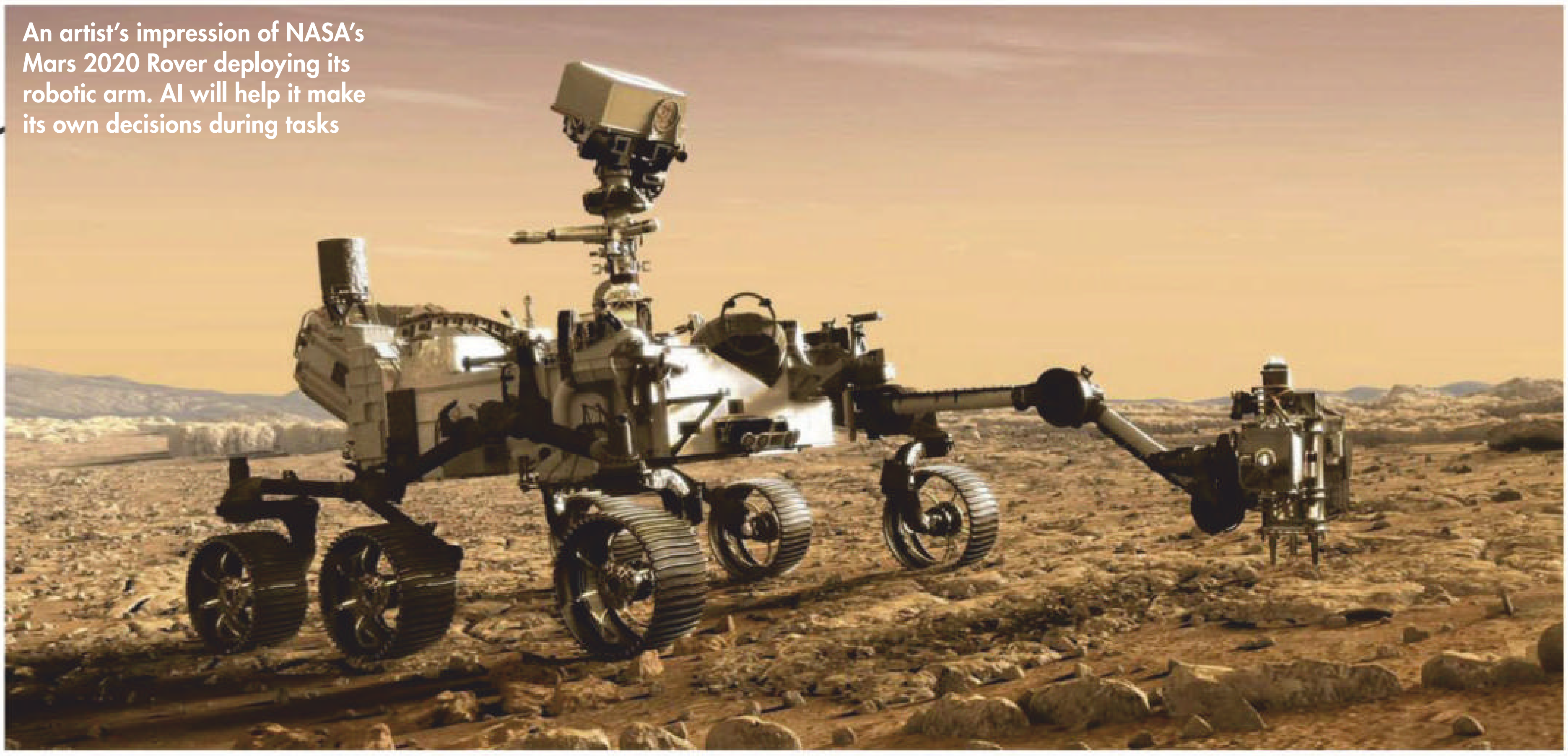
The next generation of rover, however, will be able to do much more, programmed not only to drive itself, but to plan its own tasks. Currently, human scientists direct what the rover does and when. The 2020 version will be able to analyse data itself, allowing it to work out how much time to spend on a task. If it completes one early, the rover will either move on or decide to spend higher-quality time on the original assignment, for instance taking a 4x4 image mosaic instead of the 3x3 scientists requested.

"We're very excited about that," Chien says, and not just because of the obvious increase in rover efficiency. By allowing some autonomy in future missions, multiple rovers will be able to team together, exploring not only Mars's surface, but its caves. They'll connect through a dynamic allocation algorithm, a computer system technique for allocating memory. This will help the group of rovers to decide which part of the cave each will map. Then when one rover dies and can't send feedback to the team, others can take over. ▸



Curiosity's photograph of drilling sites on Mars – but future rovers will decide how to use their own time

"The next generation of Mars rover will be able to do much more – not only driving itself, but planning its own tasks"


An artist's impression of NASA's Mars 2020 Rover deploying its robotic arm. AI will help it make its own decisions during tasks

NASA/JPL-CALTECH X 2, NASA/JPL-CALTECH/MSSS

Finding life on Europa

Cracking open the icy world requires someone intelligent at the helm

We often talk about finding life on other planets, but what about on moons? Specifically, NASA's interest lies in Europa, Jupiter's smallest Galilean satellite. Europa has a subsurface ocean – and where there's water, there's possibly life.

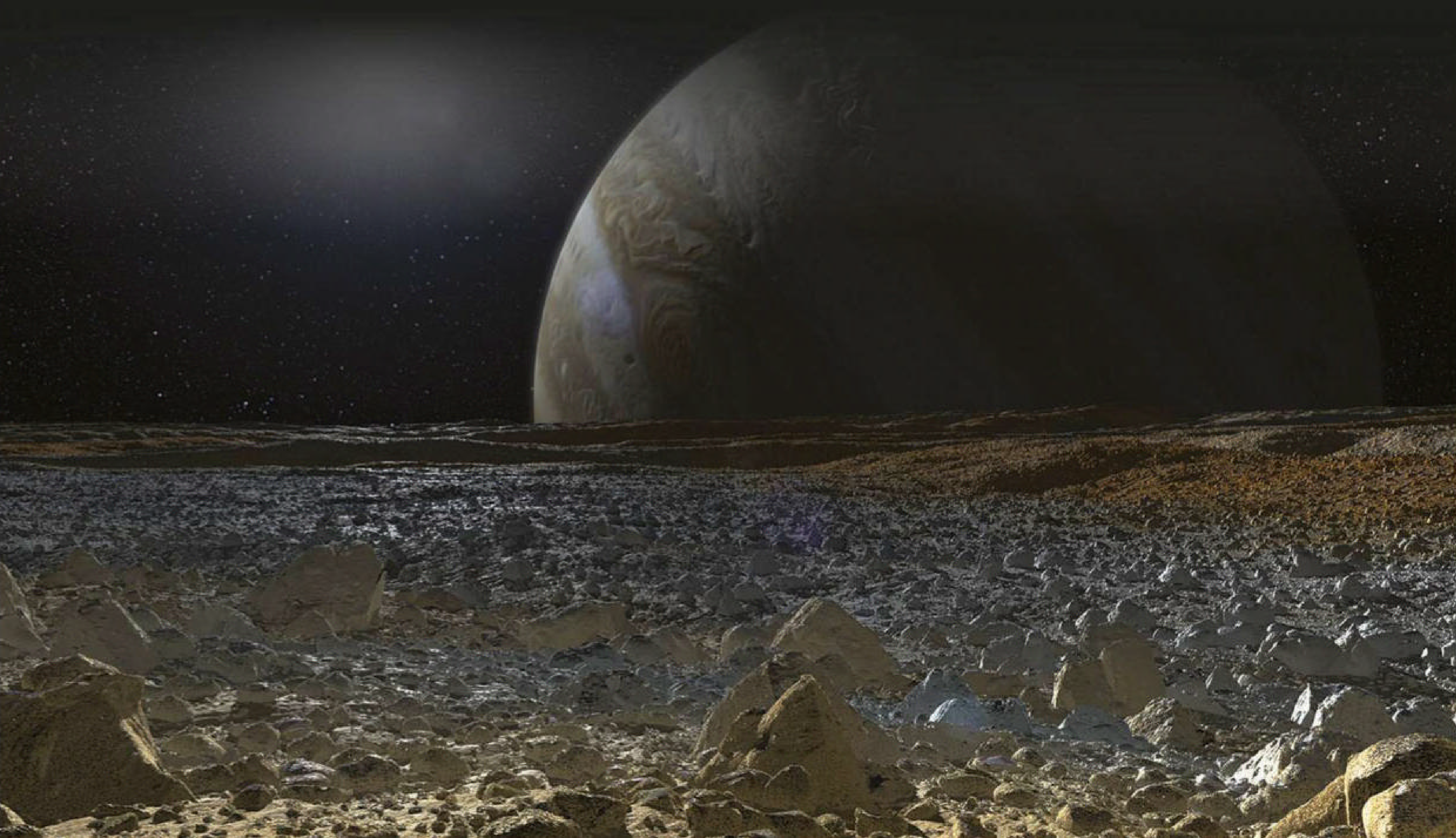
"Before the 1970s," Chien explains, "scientists thought that life could only exist in the presence of sunlight, where you could have photosynthesis. Interestingly enough, they turned out to be wrong." Even on Earth, the ocean bottom harbours life inside black smokers, a type of hydrothermal vent that Chien says may be where our planet's life initially began.

On Europa, though, the search has been difficult. The moon falls within Jupiter's radiation belt, which can severely disrupt any spacecraft's electronics and reset them. To get the images researchers need, Chien says any spacecraft NASA sends "has to be prepared to be reset up to five times per flyby. So we need AI to dynamically recover as quickly as possible from those resets in order to conduct our science mission."

But there's more, Chien says: "We want to land on Europa." Europa Lander is a mission concept that, if launched, would look for organic matter on the moon's surface. And it's a project, he says, NASA can't execute without AI. "We want to go to Europa, we want to land on this icy surface… and we want to melt through this icy crust." Artificial intelligence would direct this work, which Chien explains would take about one year. Once NASA cracks through, an AI-programmed submersible would then search for hydrothermal vents and the fine gradients that show where they might exist.

"As an AI person, what could be more exciting than finding life and knowing that AI was essential to that?" Chien asks. There is currently a funding shortfall, though – of the $19.9 billion NASA has for 2019, Europa Lander's budget is nil.

▲ An artist's rendering of the proposed AI-controlled Europa Lander

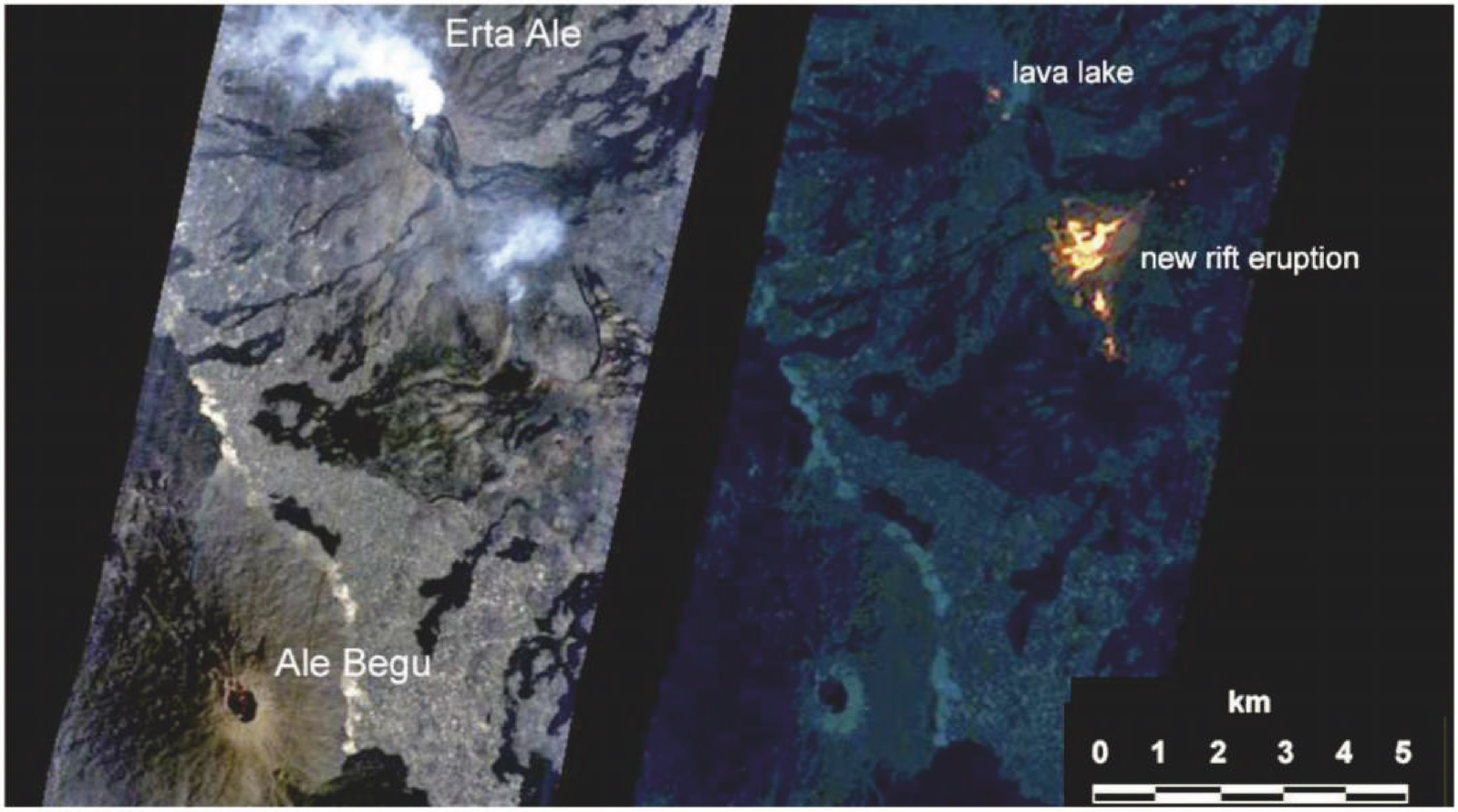


▼ A depiction of Europa's icy surface, which the craft would analyse

NASA/JPL-CALTECH, NASA, NASA/GSFC/JPL-CALTECH/ASHLEY DAVIES

Tracking disasters on Earth

Some of the most important work being done by AI is happening a little closer to home



▲ **AI onboard NASA'S EO-1 spacecraft guided imaging of the eruption of Ethiopian volcano Erta Ale in 2017**

NASA doesn't just explore outer space; the agency also seeks to learn about Earth. So does its AI. In 2017, NASA completed the Earth Observing-1 (EO-1) Mission, flying a satellite loaded with revolutionary land-imaging technology. "This spacecraft was completely under the control of artificial intelligence software. There was no human in the loop," says Chien.

The AI collected sensory data and images, and analysed them for things like volcano activity and changes in the cryosphere, the part of Earth's system made up of frozen water. The AI was also able to track worldwide flooding and other natural disasters. For example, the program took pictures of Mount Etna in Sicily in order to compare its thermal output to a baseline. "Based on that knowledge," Chien continues, "it can actually react differently. It can say, 'This is a very high-priority observation we need to analyse, get the data down quickly.' It can say, 'I need to monitor this volcano, observe it more.'"

To speed up data processing, Chien says, NASA "built up a network of about a dozen to a score of satellites that can all detect and talk to each other". Should a single craft or ground sensor detect an erupting volcano, the network processes that data without human involvement. The system actually detected Icelandic volcano Eyjafjallajökull's 2010 eruptions before first responders did.

In 2005, NASA also began using vector machine learning to track the growth and retreat of water, snow and ice. Working with data from Eyjafjallajökull and others, Chien says, the AI can discriminate between the ice that's on the ground, an ash plume and the shadow of that ash plume. It then analyses this information against the Sun and the spacecraft's positions to calculate ash plume height. "That's very interesting to a scientist because that tells them how vigorously that volcano is erupting," he explains.

This helps NASA monitor climate change by assessing how glaciers are melting: "The volcanoes are underneath these huge glaciers," says Chien. "The first sign to detect a volcano erupting is increased liquid flow at the edge of that glacier." This work, he contends, is, "some of our most sophisticated processing. Imaging spectroscopy takes a sensor and can actually view things in hundreds of different spectral wavelengths." These wavelengths detect alunite, calcite and other minerals and gases. The AI then detects methane and carbon dioxide emissions, an ability which also helps NASA identify natural gas pipeline leaks and climate change treaty violations.

Whether it's pushing at the boundaries of exploration at other planets, or helping to monitor our own, it's clear that AI is the future at NASA.

ABOUT THE WRITER
Terena Bell is a technology and science writer and journalist based in the US, whose work has appeared in *The Washington Post*

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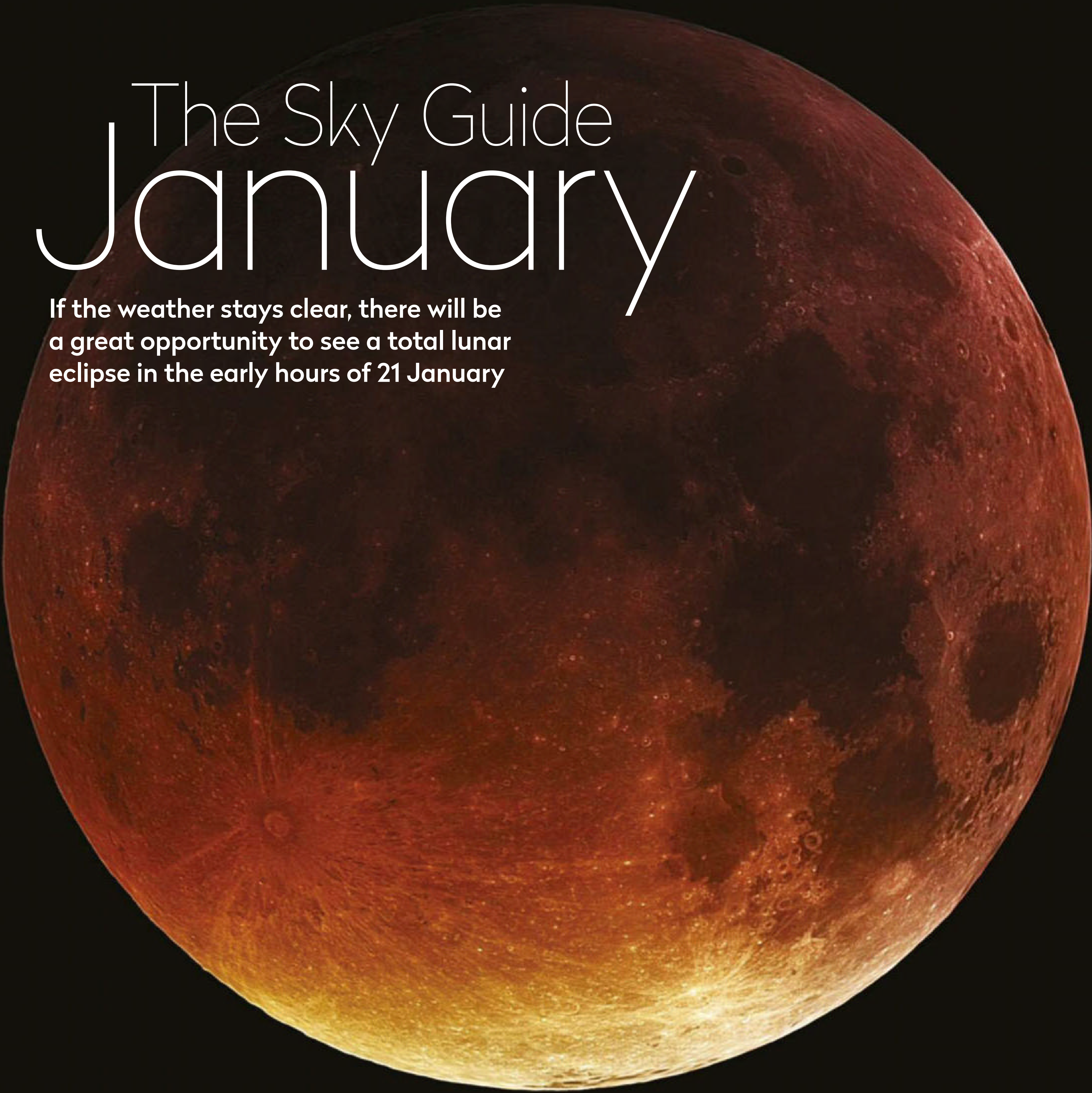
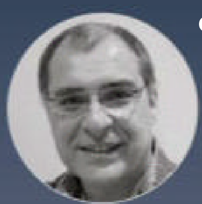
The Sky Guide January

If the weather stays clear, there will be a great opportunity to see a total lunar eclipse in the early hours of 21 January

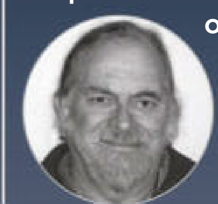


PETE LAWRENCE

ABOUT THE WRITERS



Pete Lawrence is an astronomer and astro imager who presents *The Sky at Night* monthly on BBC Four



Stephen Tonkin is a binocular observer. Find his tour of the best sights for both eyes on page 60

RED LIGHT FRIENDLY

To preserve your night vision, this Sky Guide can be read using a red light under dark skies

DON'T MISS...

✦ A favourable Quadrantid meteor shower peak
✦ Mercury, Venus, Jupiter and the Moon put on a morning show
✦ Two comets in Lynx

JANUARY **HIGHLIGHTS**

Your guide to the night sky this month

TUESDAY 1

Mag. –4.4 Venus appears close to a 21%-lit, waning crescent Moon in the morning sky. View this beautiful pairing from around 05:00 UT.

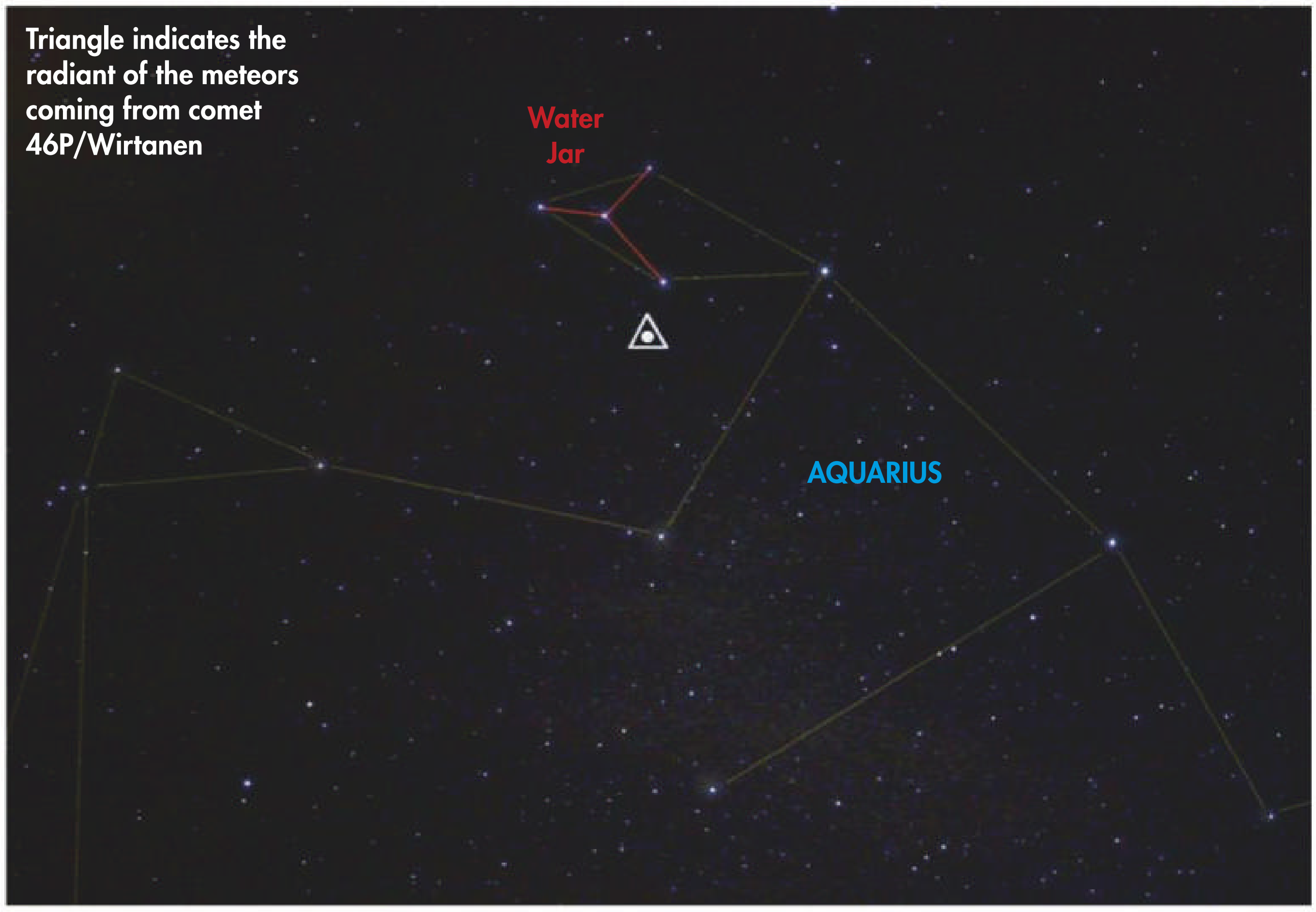
◀ WEDNESDAY 2

Don't miss this morning's stunning Solar System line-up of Venus, a 13%-lit waning crescent Moon, mag. –1.6 Jupiter and mag. –0.4 Mercury. Venus and the Moon will be first to appear low in the south-southeast at 05:00 UT. Mercury will appear last around 07:30 UT.

FRIDAY 4 ▶

The annual Quadrantid meteor shower peaks at 02:00 UT (see page 53).

Also, dust ejected from comet 46P/Wirtanen in 1974 may produce a low-rate shower peaking at 18:26 UT with a radiant just south of the Water Jar asterism in Aquarius.



SUNDAY 6

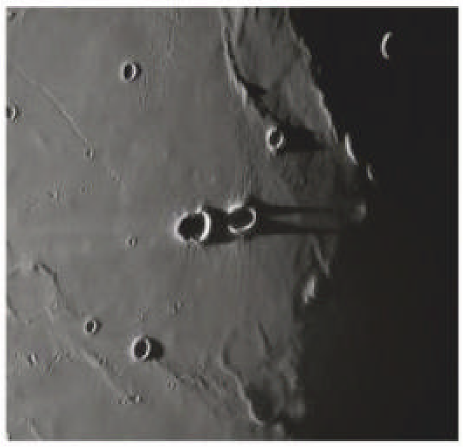
The stunning morning planet Venus reaches greatest western elongation today, appearing separated from the Sun by 47°.

SUNDAY 13

Mag. –0.6 Mercury and mag. +0.9 Saturn are just 1.8° apart in the morning sky. This will be a tricky thing to see against the bright dawn sky, both planets appearing very low in the southeast approximately 20 minutes before sunrise.

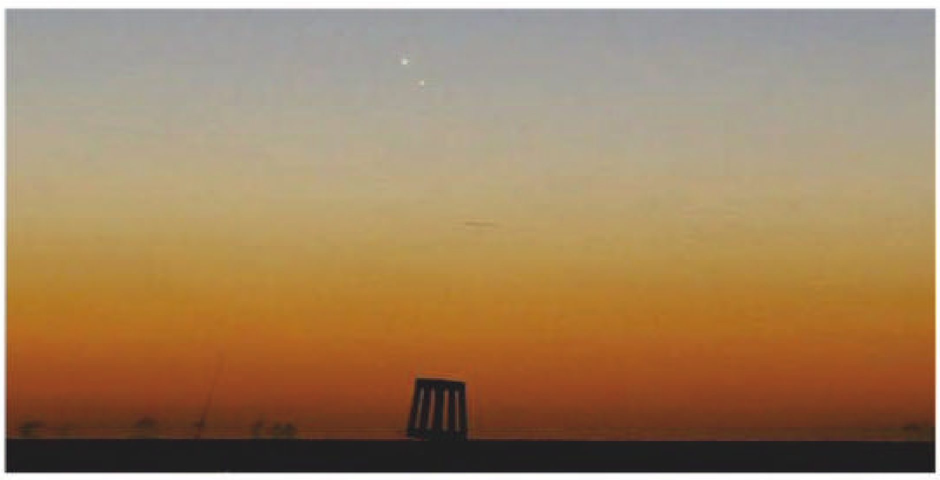
TUESDAY 15

Minor planet 433 Eros is closest to Earth today. It appears as a mag. +9.1 object in Perseus, 6° east of mag. +2.9 Epsilon (ε) Persei at 00:00 UT. Its distance from Earth is 0.209 AU or 81.4 lunar distances.



◀ WEDNESDAY 16

Around 23:00 UT you can see the lunar clair obscur effect known as the Twin Spires of Messier. Sunlight passing over craters Messier and Messier A produces two distinct spikes, completely different to what you'd expect to see.



PETE LAWRENCE X 8

◀ TUESDAY 22

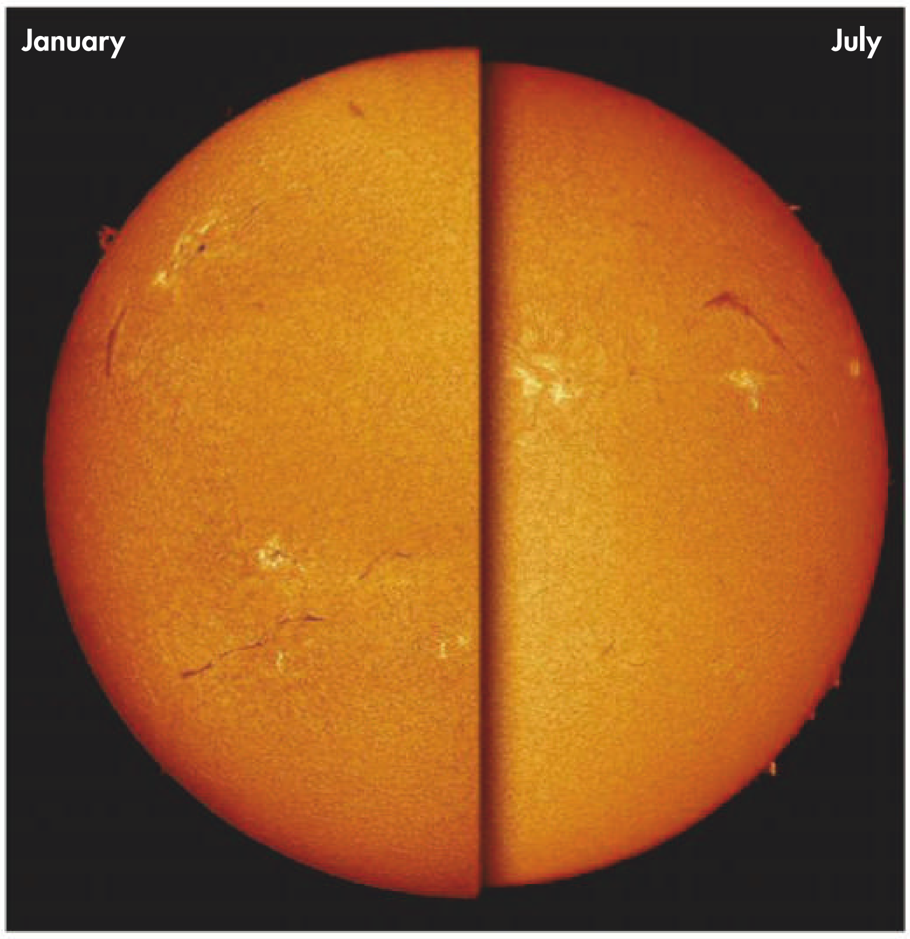
Appearing low above the southeast horizon at 05:45 UT, mag. –1.7 Jupiter will be 2.5° from mag. –4.2 Venus this morning. If the sky is clear, this will be a stunning sight.

WEDNESDAY 23

The bright star that can be seen 2° below this morning's 94%-lit, waning gibbous Moon is mag. +1.9 Regulus (Alpha (α) Leonis).

THURSDAY 3

Earth reaches perihelion at 05:19 UT, the point in its orbit when it's closest to the Sun. The distance separating them will be 147,099,760km at this time (0.9833 AU). This is also when the Sun's apparent diameter will appear at its largest.



SATURDAY 5

Comets 46P/Wirtanen and 38P/Stephan-Oterma are currently both in the constellation of Lynx. With the Moon out of the way, this is a great time to look for them. Turn to pages 53 and 59 for further information.

MONDAY 7

The Moon sets early enough to allow this month's Deep Sky Tour region to be well positioned under dark skies for the next few evenings (see page 62). This month we're investigating the area of sky around the foot of Castor in Gemini, the Twins.

SATURDAY 12

This evening look out for the 35% waxing crescent Moon positioned 6.3° below mag. +0.6 Mars.

THURSDAY 17

As the sky darkens look out for mag. +0.8 Aldebaran 1° below an 84%-lit, waxing gibbous Moon. Using a telescope look at the southern 'cusp' of Sinus Iridum for the clair obscur effect known as Cassini's Moon Maiden.

MONDAY 21

A total eclipse of the Moon will occur this morning. Turn to page 52 for further details. The eclipsed Moon will lie 7° west of M44, the Beehive Cluster.

This full Moon is the first of three perigean Moons for 2019, the February one being the closest.

THURSDAY 31

Mag. –1.7 Jupiter, mag. –4.1 Venus and a crescent Moon sit together in this morning's sky. The 18%-lit waning crescent Moon will be positioned between both planets. All three objects can be seen low in the southeast from around 05:30 UT.

FAMILY STARGAZING – ALL MONTH

The total lunar eclipse on the morning of 21 January is a perfect event to observe with budding astronomers, apart from the timing! The main visual eclipse takes place between 03:34 UT and 06:51 UT – with totality between between 04:41 UT and 05:43 UT – so you'll need an early night on 20 January. It's sometimes difficult to wake up in the early hours to observe, so set two alarms and have breakfast ready, because this naked-eye event has the potential to be something that young eyes will remember forever. Turn to page 52 for more information.

www.bbc.co.uk/cbeebies/shows/stargazing

NEED TO KNOW

The terms and symbols used in *The Sky Guide*

UNIVERSAL TIME (UT) AND BRITISH SUMMER TIME (BST)

Universal Time (UT) is the standard time used by astronomers around the world. British Summer Time (BST) is one hour ahead of UT.

RA (RIGHT ASCENSION) AND DEC. (DECLINATION)

These coordinates are the night sky's equivalent of longitude and latitude, describing where an object is on the celestial 'globe'.

FAMILY FRIENDLY
Objects marked with this icon are perfect for showing to children

NAKED EYE
Allow 20 minutes for your eyes to become dark-adapted

PHOTO OPP
Use a CCD, planetary camera or standard DSLR

BINOCULARS
10x50 recommended

SMALL/ MEDIUM SCOPE
Reflector/SCT under 6 inches, refractor under 4 inches

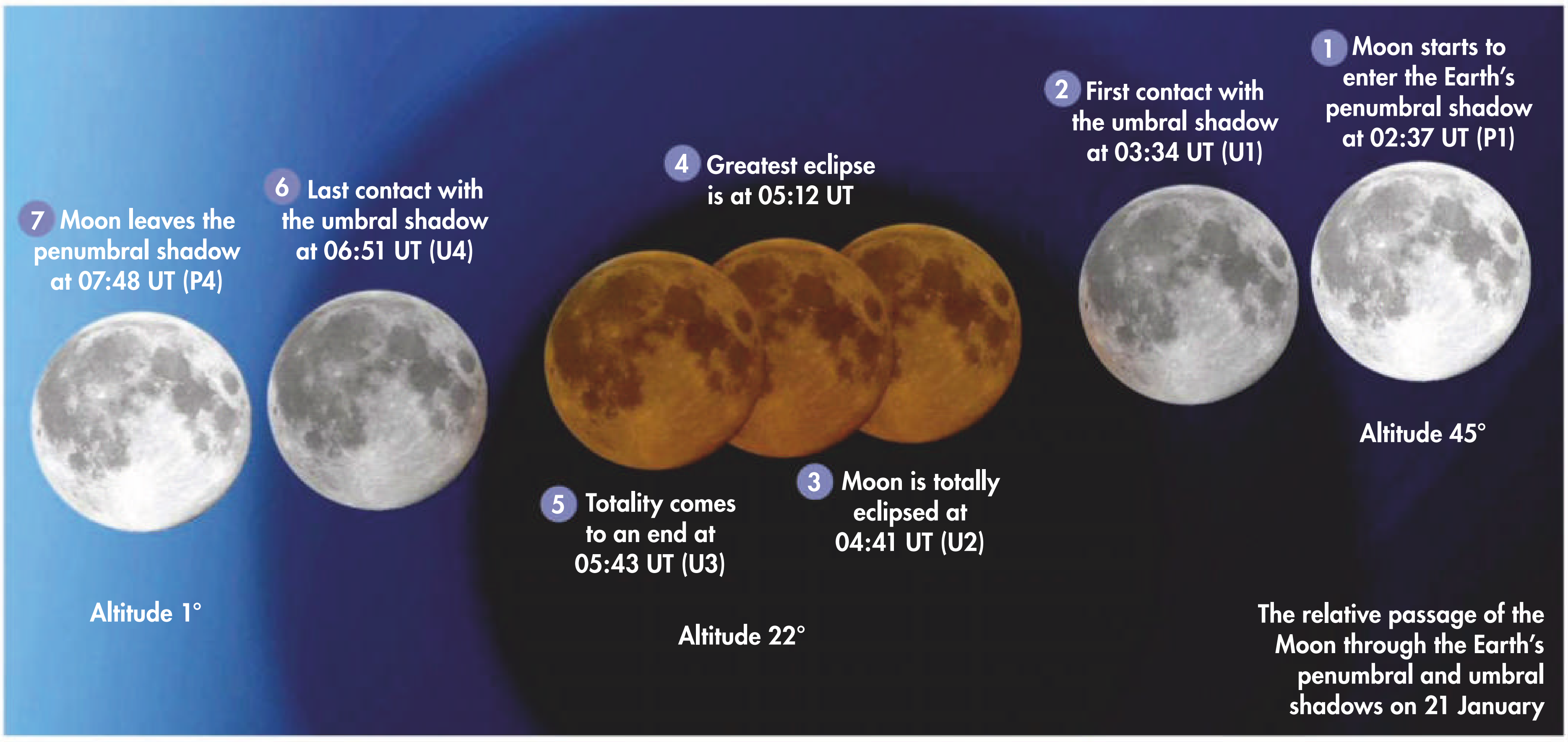
LARGE SCOPE
Reflector/SCT over 6 inches, refractor over 4 inches

GETTING STARTED IN ASTRONOMY

If you're new to astronomy, you'll find two essential reads on our website. Visit http://bit.ly/10_Lessons for our 10-step guide to getting started and http://bit.ly/First_Tel for advice on choosing a scope.

THE BIG **THREE**

The three top sights to observe or image this month



The relative passage of the Moon through the Earth's penumbral and umbral shadows on 21 January

DON'T **MISS**

Total Lunar Eclipse

BEST TIME TO SEE: 21 January from 03:34 UT until 07:00 UT

The Moon enters the Earth's umbral shadow in the early hours of 21 January producing a total lunar eclipse. Given clear skies, the entire event will be visible from across the UK.

The Earth's shadow at the distance of the Moon has two parts: a dark inner umbra surrounded by a lighter penumbra, arranged like the inner and outer bullseye at the centre of a dart board. The Moon's edge first touches the penumbral shadow (P1) at 02:37 UT, when it will be at an altitude of around 20° in the southwest, between Cancer and Gemini. However, you probably won't be able to see any signs of this weak shadow at this point.

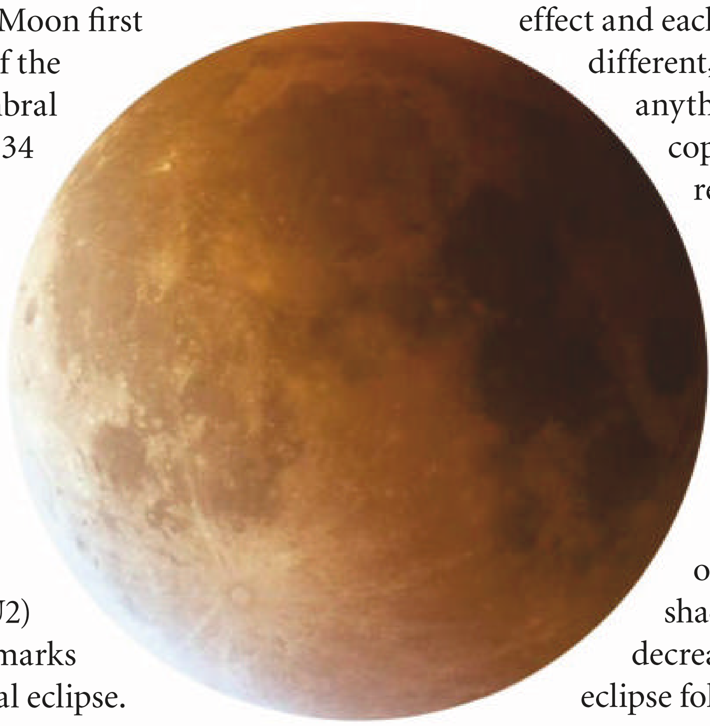
Looking at the Moon's disc at P1 shows it to be completely full, an event that is rarer than you might realise. A 'normal' non-eclipse full Moon passes just north or south of the Earth's shadow. Consequently, a telescopic view of a regular full Moon still shows a tiny sliver of terminator shadows at the extreme north or south of the lunar disc.

As the Moon creeps deeper into the penumbra, the shadow's intensity increases and you should eventually be able to detect its presence. On page 61 is this month's Challenge: to see how early you can spot evidence of the penumbral shadow.

The edge of the Moon first touches the edge of the darker, central umbral shadow (U1) at 03:34 UT, marking the start of the first partial phase of the eclipse.

The partial eclipse grows in depth until the following edge of the Moon reaches the edge of the umbral shadow (U2) at 04:41 UT. This marks the start of the total eclipse. The Moon continues to move into the umbra, reaching the point of greatest eclipse at 05:12 UT. For this particular eclipse, the centre of the Moon lies half an umbral shadow radius north of the shadow's centre at greatest eclipse, so expect the northern edge of the Moon to appear brighter than the southern edge.

Although the umbral shadow represents the Sun's light being completely blocked by the Earth, our atmosphere refracts sunlight into the shadow. As our atmosphere is good at scattering blue light, the infill light is mostly orange and red. Consequently the Moon's disc will typically appear orange during a total lunar eclipse. The clarity of Earth's atmosphere also has an effect and each eclipse is different, appearing anything from a light coppery yellow to a really dark brown that virtually disappears against the background sky.



▲ As the end of totality approaches at around 05:43 UT (U3) the western edge of the Moon will appear to brighten

Totality ends at 05:43 UT (U3) when the Moon reaches the far side of the umbral shadow. A second, decreasing partial eclipse follows with the Moon leaving the umbral shadow completely at 06:51 UT (U4) as the dawn sky starts to brighten. The departure from the penumbra will be complete at 07:48 UT (P4), with the Moon hanging low above the west-northwest horizon in a twilight sky.

PETE LAWRENCE X 4

Favourable Quadrantids

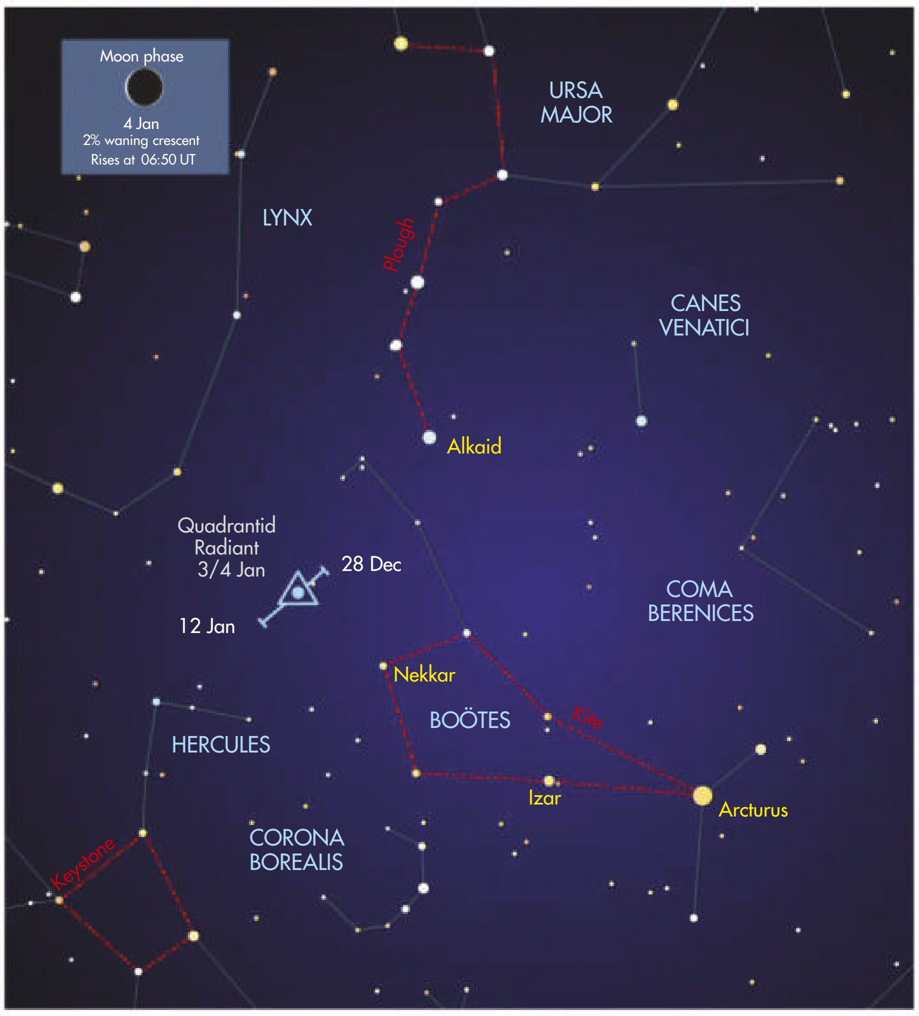
BEST TIME TO SEE: 00:00 UT to 06:00 UT on 4 January

The Quadrantid meteor shower peaks on the night of 3/4 January. This is one of the most prolific of the annual showers, with a zenithal hourly rate (ZHR) of 120 meteors per hour. The reason Quadrantids don't get as much press as the August Perseids or December Geminids is twofold. First, by 3/4 January most people are experiencing a post-festive period ethusiasm defecit. Also, the period of peak activity is narrow. The Quadrantids are active from 28 December to 12 January but rates outside of the peak period are low: typically, there's a four-hour window when rates are above half the maximum value.

The shower gets its name from the now defunct constellation of Quadrans Muralis. In modern times, the radiant at peak activity lies within the northern boundary of Boötes, the Herdsman.

This year's peak is expected at 02:00 UT on 4 January and, with a new Moon on 6 January, conditions couldn't be better. The radiant position is circumpolar from the UK, but only starts to reach a decent altitude after midnight. At 02:00 UT it will be 35° above the northeast horizon.

Observe the shower from a site well away from any light sources and use something like a sunlounger so you can comfortably look up at an altitude of around 60°. If you can manage it, a session from midnight through to 04:00 UT will deliver the best results.



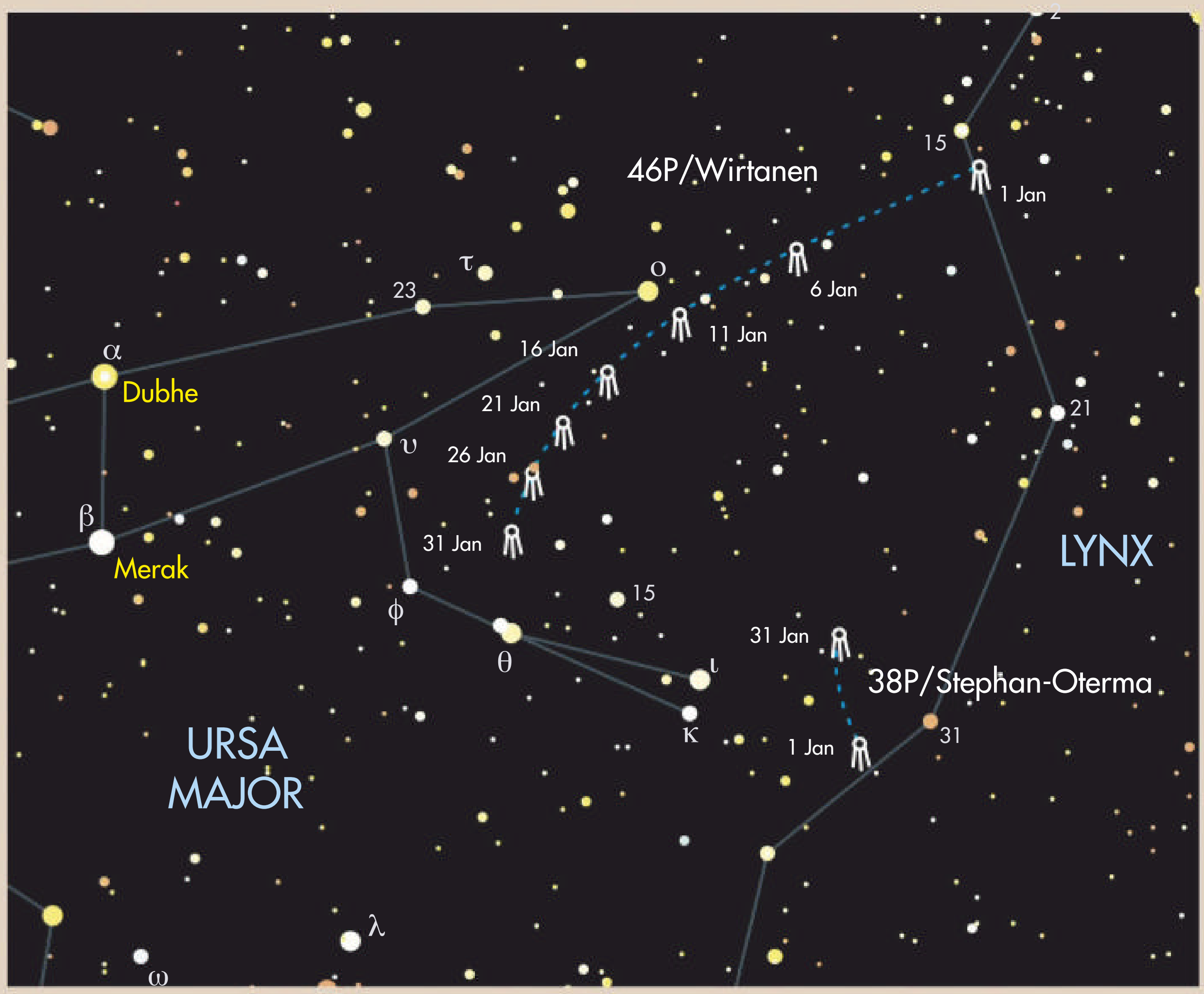
▲ Be alert for the brief peak of the Quadrantid meteor shower

Fading Wirtanen

BEST TIME TO SEE: Early January

At the time of writing, the performance of comet 46P/Wirtanen is still uncertain. Hopefully, it will have brightened enough to be seen with the naked eye while moving north through the sky during December. Its path ended 2018 in the constellation of Lynx and this is where it can be found at the start of January, 1.2° to the south-southeast of 15 Lynxis. Predicted to be a tricky mag. +5.0 object at this time, 46P arcs across the Lynx/ Ursa Major border, ending up in Ursa Major from the middle of the month.

The reason why we describe it as a tricky mag. +5.0 is that the head of the comet may have a reasonable apparent size and this will result in a low surface brightness, making it harder to see than its magnitude would suggest. At the end of the month, 46P/Wirtanen is predicted to have faded to mag. +7.8 which means



▲ Both comets 46P/Wirtanen and 38P/Stephan-Oterma will be hanging around Lynx in January

that, in theory at least, it should be possible to see with binoculars.

The Moon is full on 21 January and at this time of year the fuller phases ride high across the UK's sky, making hunting diffuse comets somewhat tricky. Your best chance of seeing it will be at the start of the month, as the new Moon is on 6 January. The best date for star-hopping to it will be 11 January, when 46P lies just over a degree from mag. +3.4 Omicron (ο) Ursae Majoris.

THE NORTHERN HEMISPHERE IN JANUARY

KEY TO STAR CHARTS

Arcturus	STAR NAME
PERSEUS	CONSTELLATION NAME
	GALAXY
	OPEN CLUSTER
	GLOBULAR CLUSTER
	PLANETARY NEBULA
	DIFFUSE NEBULOSITY
	DOUBLE STAR
	VARIABLE STAR
	THE MOON, SHOWING PHASE
	COMET TRACK
	ASTEROID TRACK
	STAR-HOPPING PATH
	METEOR RADIANT
Circlet	ASTERISM
	PLANET
	QUASAR

STAR BRIGHTNESS:

- MAG. 0 & BRIGHTER
- MAG. +1
- MAG. +2
- MAG. +3
- MAG. +4 & FAINTER

N E S W — COMPASS AND FIELD OF VIEW

MILKY WAY

CHART: PETE LAWRENCE

WHEN TO USE THIS CHART

1 JANUARY AT 00:00 UT
15 JANUARY AT 23:00 UT
31 JANUARY AT 22:00 UT

On other dates, stars will be in slightly different positions because of Earth's orbital motion. Stars that cross the sky will set in the west four minutes earlier each night.

HOW TO USE THIS CHART

1. **HOLD THE CHART** so the direction you're facing is at the bottom.
2. **THE LOWER HALF** of the chart shows the sky ahead of you.
3. **THE CENTRE OF THE CHART** is the point directly over your head.

SUNRISE/SUNSET IN JANUARY*

DATE	SUNRISE	SUNSET
1 Jan 2019	08:26 UT	16:01 UT
11 Jan 2019	08:22 UT	16:15 UT
21 Jan 2019	08:12 UT	16:31 UT
31 Jan 2019	07:57 UT	16:50 UT

MOONRISE IN JANUARY*

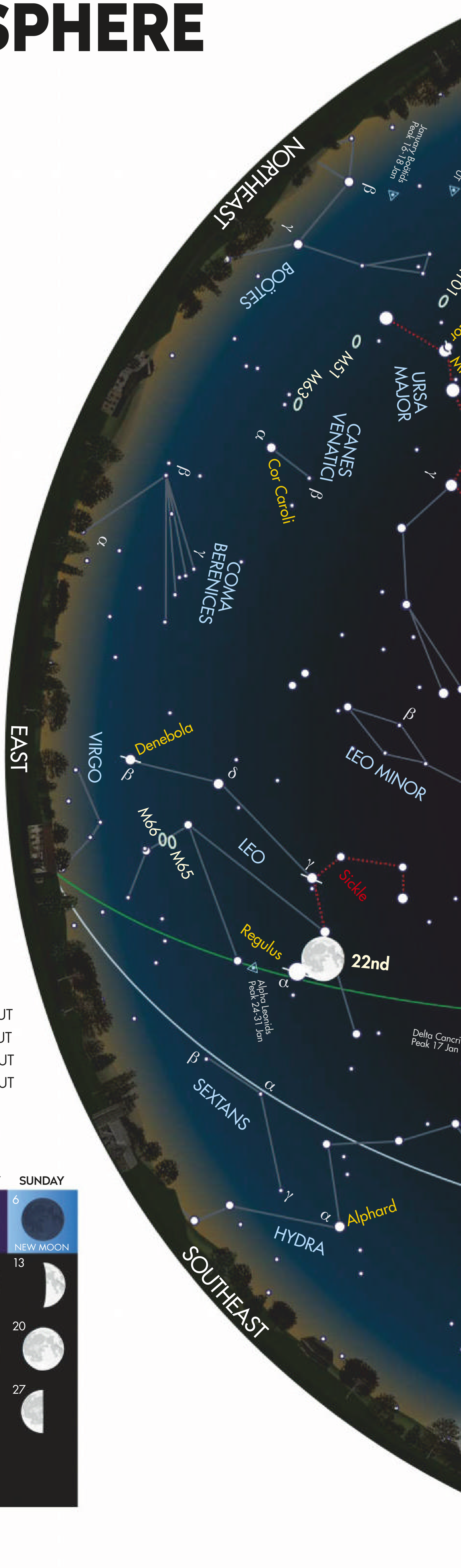
MOONRISE TIMES

1 Jan 2019, 03:25 UT	17 Jan 2019, 13:08 UT
5 Jan 2019, 07:48 UT	21 Jan 2019, 17:00 UT
9 Jan 2019, 10:18 UT	25 Jan 2019, 22:38 UT
13 Jan 2019, 11:35 UT	29 Jan 2019, 02:27 UT

*Times correct for the centre of the UK

LUNAR PHASES IN JANUARY

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
	1	2	3	4	5	6 NEW MOON
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21 FULL MOON	22	23	24	25	26	27
28	29	30	31			



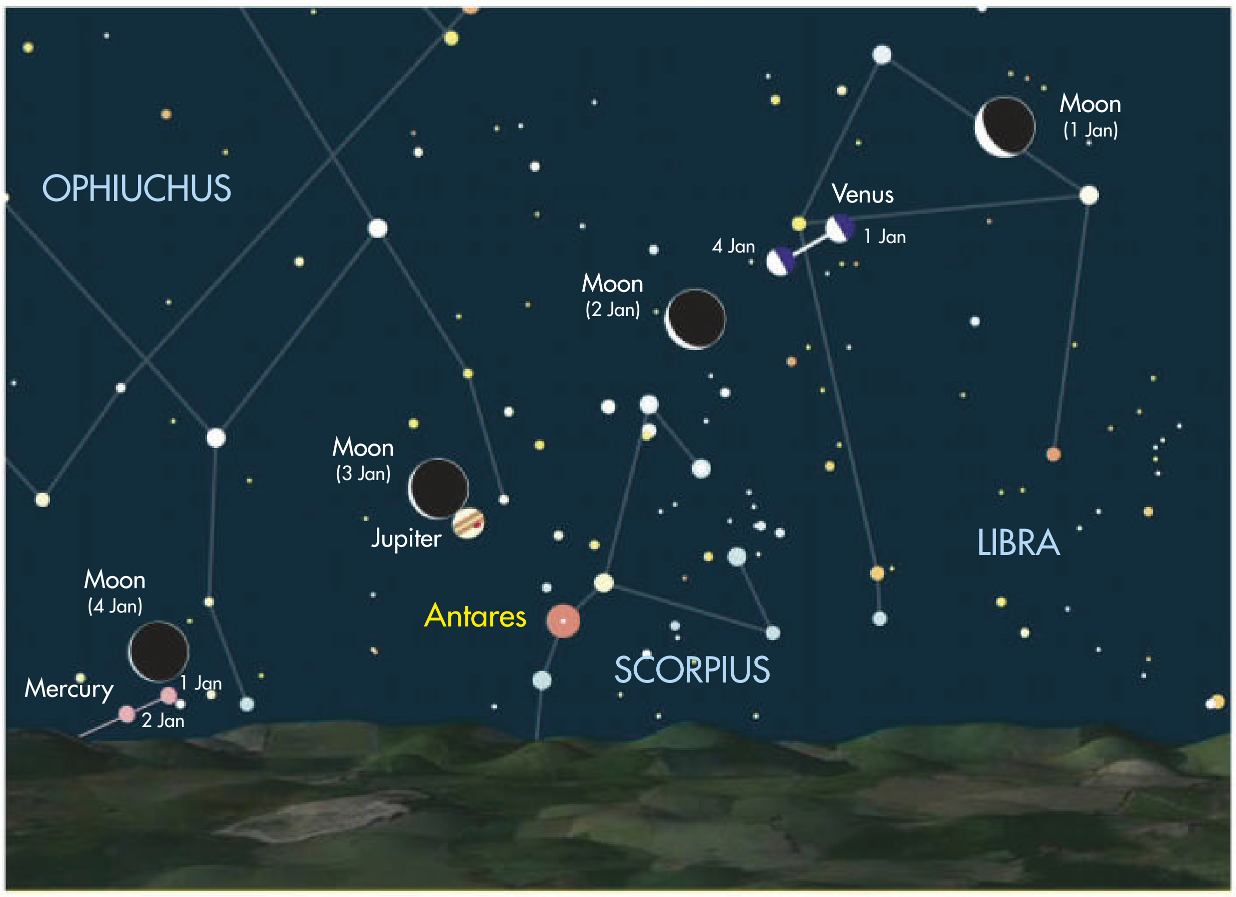
YOUR BONUS CONTENT
Paul and Pete's Virtual Planetarium

THE **PLANETS**

PICK OF THE MONTH

Venus

Best time to see: 31 January, from 06:00 UT
Altitude: 5° (low)
Location: Ophiuchus
Direction: Southeast
Features: Phase, subtle disc shadings
Equipment: 75mm or larger

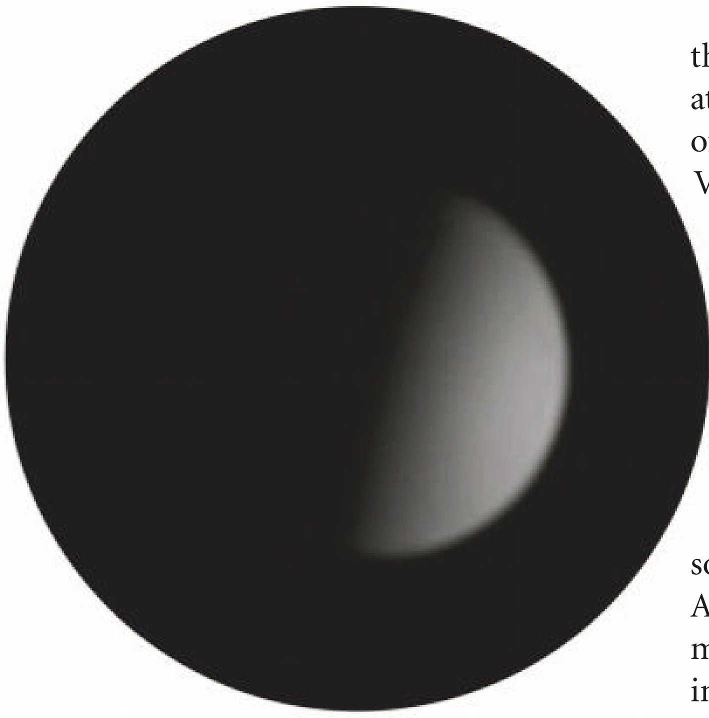


▲ There's a busy start to the year as Venus and Jupiter are joined by the waning crescent Moon, with Mercury also making an appearance just before sunrise on 1 and 2 January

Venus is currently a morning planet shining brighter than mag. –4.0 all month. On the mornings of 1 and 2 January the planet's naked-eye appearance will be enhanced by the presence of a waning crescent Moon. On New Year's morning the Moon will be 21% lit and appear to the west-northwest of the planet – that's above and right as seen from the UK. The following morning, the now 13% lit, waning crescent Moon swaps sides to lie to the east-southeast of Venus. The separation of about 4.3° will make for a particularly attractive sight on 2 January. As the dawn sky brightens so Venus and the Moon will be joined by mag. –1.6 Jupiter and then mag. –0.4 Mercury.

Through a telescope Venus currently appears close to half lit. According to calculations, Venus should appear perfectly 50% illuminated on the day of its greatest western elongation, which is 6 January. However, owing to an effect known as the phase anomaly when Venus is in the morning sky, it appears that this event happens late by a few days. Phase anomaly is thought to be due to the way sunlight scatters in the planet's atmosphere. Record your own estimates of the phase by imaging or sketching Venus through a telescope over the days running up to and from greatest western elongation, to pinpoint when you think the planet looks exactly half-lit.

Later in the month, look out for a close encounter between Venus and mag. –1.7 Jupiter. On 23 January both planets appear separated by just 2.5°, and should be a stunning sight low in the southeast as they rise around 05:00 UT. As the pair separate over the following mornings, there's an additional point of interest on the very last day of the month when an 18%-lit waning lunar crescent once again joins the scene and appears to lie between both planets.

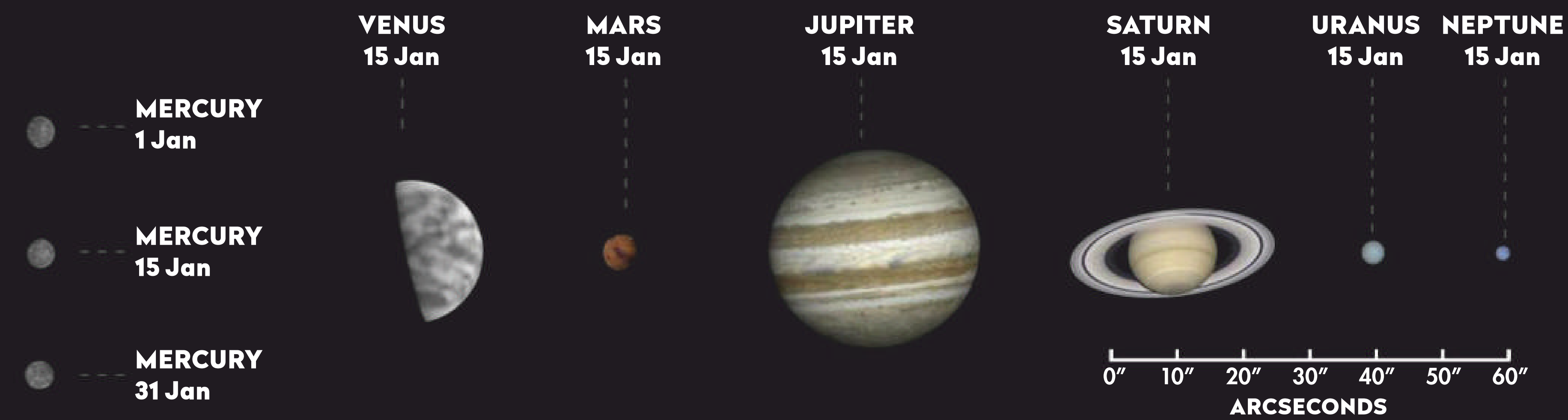


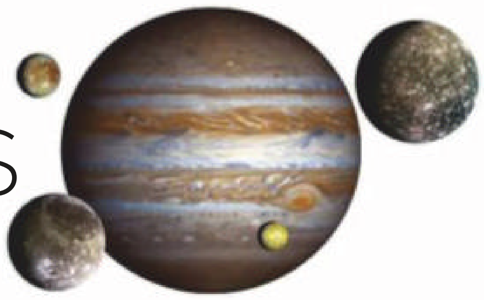
▲ Mathematically, Venus will be half-lit on 6 January, but in practice it may not appear that way, because of an atmospheric effect

PETE LAWRENCE X 4

THE PLANETS IN JANUARY

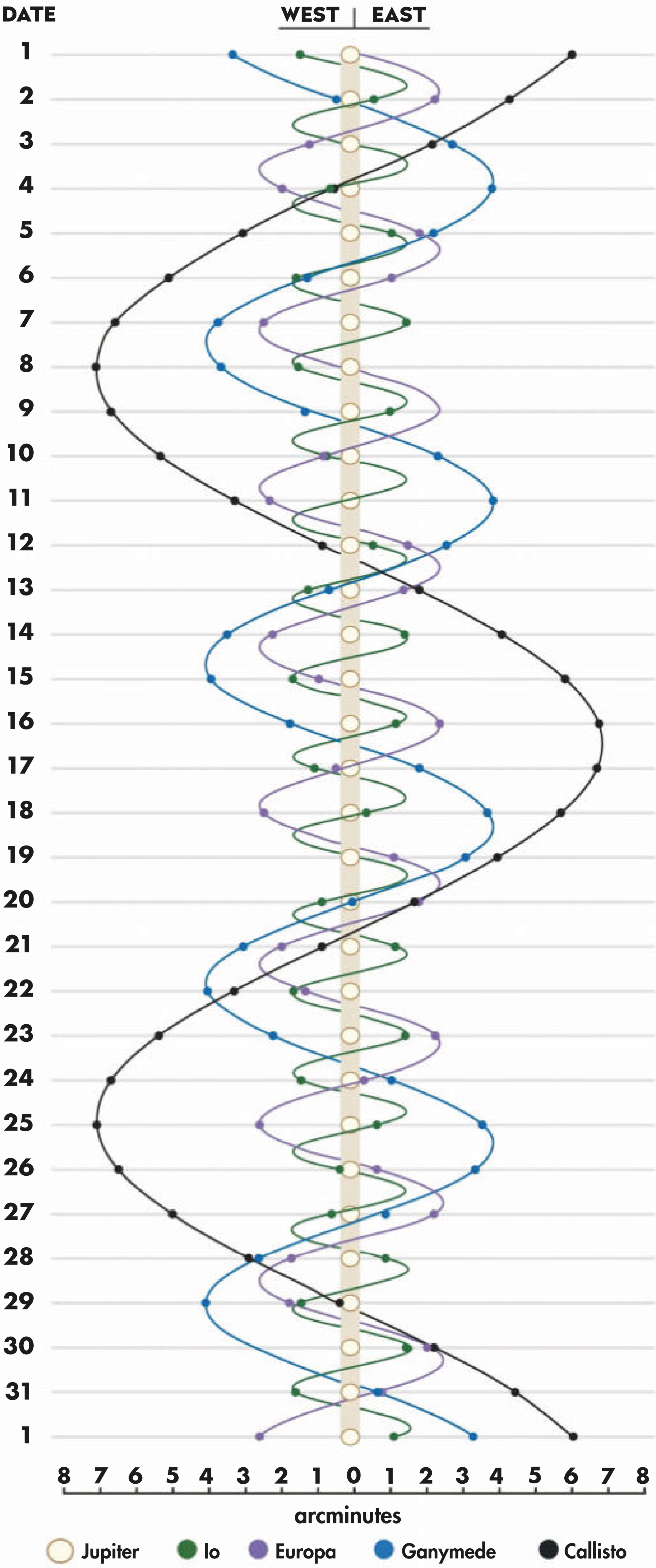
The phase and relative sizes of the planets this month. Each planet is shown with south at the top, to show its orientation through a telescope





JUPITER'S MOONS JANUARY

Using a small scope you'll be able to spot Jupiter's biggest moons. Their positions change dramatically during the month, as shown on the diagram. The line by each date on the left represents 00:00 UT.



Mercury

Best time to see: 1 January, 30 minutes before sunrise
Altitude: 1.5° (very low)
Location: Sagittarius
Direction: Southeast

Mercury starts January as a morning object but is so close to the Sun it's difficult to see. On 1 January it's at mag. –0.4, appearing about an hour before sunrise above the southeast horizon. Superior conjunction occurs on 30 January.

Mars

Best time to see: 1 January, 18:00 UT
Altitude: 36°
Location: Pisces
Direction: South

Mars is an evening object in Pisces. Through a telescope, the mag. +0.5 planet appears just 7 arcseconds across on 1 January, located southeast of the Circlet asterism. For the rest of the month Mars races east, remaining in Pisces as it goes. By the end of the month, Mars is within the narrowing wedge of stars representing the cord tying the fishes of Pisces together, slightly east of mag. +4.3 Epsilon (ε) Piscium. The planet will dim to mag. +0.9 by 31 January and telescopically will appear just 6 arcseconds across, its disc showing an 89%-lit phase.

Jupiter

Best time to see: 31 January, from 06:00 UT
Altitude: 7.5° (low)
Location: Ophiuchus
Direction: Southeast

Jupiter rises a couple of hours before the Sun at the start of January, shining at mag. –1.6 against the stars representing Ophiuchus's legs. Mag. –4.4 Venus, Jupiter and mag. –0.4 Mercury appear in a line on New Year's Day, with a 21%-lit waning crescent Moon 7° west of Venus. On 2 January, the 13%-lit waning crescent Moon sits between Venus and Jupiter. On 3 January a now 6%-lit Moon lies 2.3° north of Jupiter, an impressively close pairing. By the end of January, Venus appears to the east-northeast of Jupiter with both planets rejoined by the waning crescent Moon. On 30 January the 25%-lit waning Moon sits west of Jupiter. However, this gets better the following morning with a 17%-lit waning crescent Moon located between Venus and Jupiter – quite a spectacle for early risers.

Saturn

Best time to see: 31 January, 1 hour before sunrise
Altitude: 1.6° (very low)
Location: Sagittarius
Direction: Southeast

Saturn's too close to the Sun to be seen properly this month. It may be glimpsed with the naked eye low in the southeast towards the end of January, joining a line-up with mag. –4.1 Venus and mag –1.7 Jupiter.

Uranus

Best time to see: 1 January, 19:10 UT
Altitude: 47°
Location: Pisces
Direction: South

Uranus is a well-placed evening object at the start of January, visible around 18:00 UT on New Year's Day, close to its highest point in the sky due south. By the end of January, it will have drifted west. In theory mag. +5.8 Uranus should just be visible to the naked eye from a dark-sky location. It's currently located in Pisces.

Neptune

Best time to see: 1 January, 18:20 UT
Altitude: 25.5°
Location: Aquarius
Direction: West of south

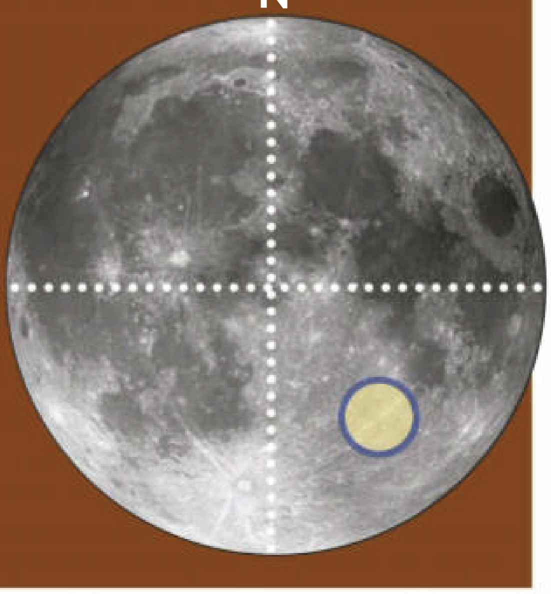
Neptune is in the southwest as darkness falls at the start of the month, then creeps westward. It's low in the west-southwest as the sky darkens at the end of January, shining at mag. +7.9 all month. You'll need at least binoculars to see it against the eastern stars of Aquarius.

YOUR BONUS CONTENT Planetary observing forms

MOON**WATCH**

Piccolomini

Type: Crater
Diameter: 88km
Longitude/latitude: 32.2° east, 29.7° south
Age: 3.2–3.8 billion years
Best time to see: Five days after new Moon (11 Jan) and four days after full Moon (25 Jan)
Minimum equipment: 2-inch refractor



> ***"At the centre of the crater is a magnificent central mountain complex"***

Piccolomini is an 88km crater situated to the south of **Mare Nectaris**. It also lies at the southern end of the distinctive **Rupes Altai**, a 480km, curved cliff structure, concentric with the edge of Mare Nectaris. The impact that formed Piccolomini occurred after the formation of Rupes Altai.

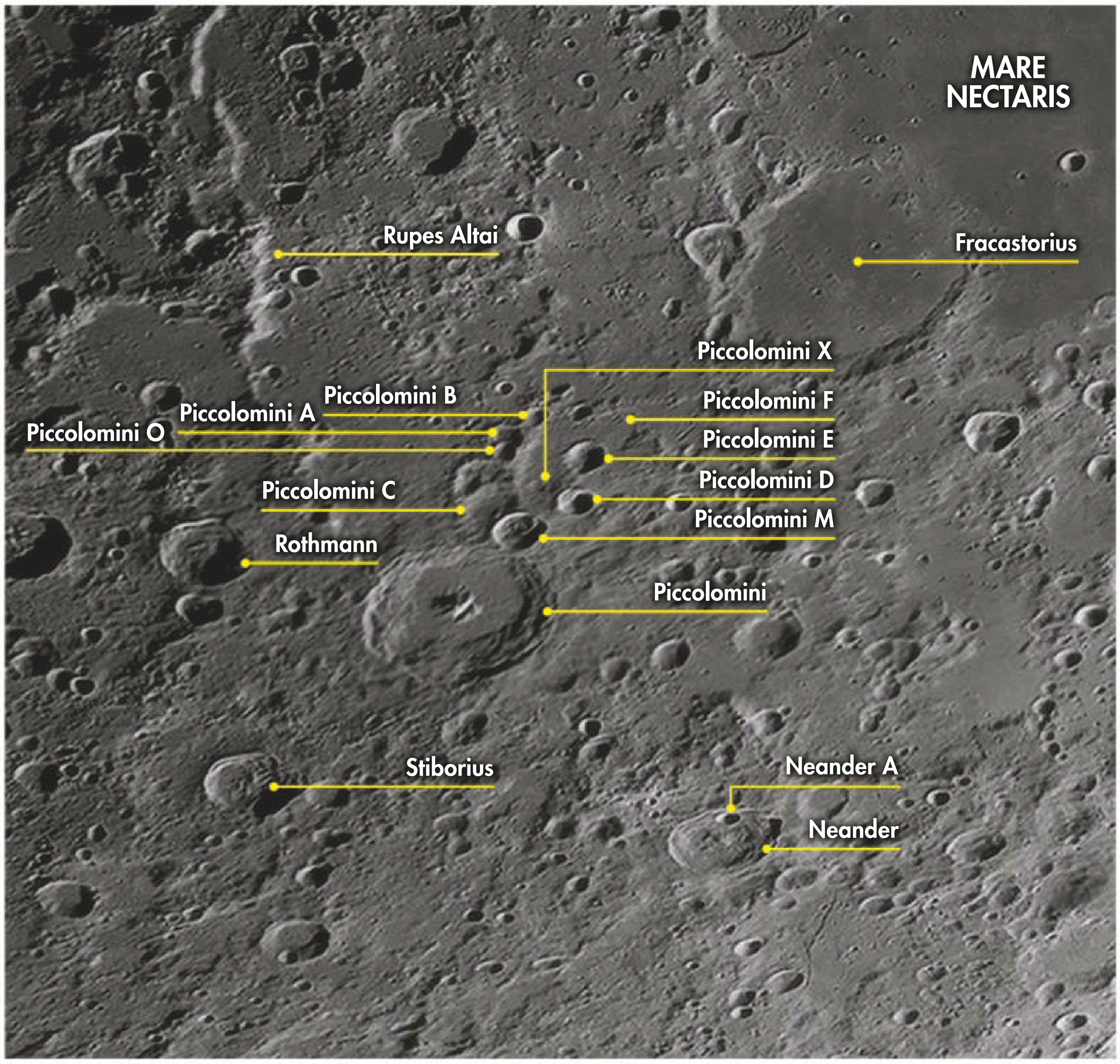
Piccolomini is embedded within a bright highland landscape and this makes the crater somewhat tricky to see under high illumination. During periods when the terminator is nearby, the crater shows a wealth of detail. Piccolomini is around 4.2km deep measured rim to floor, with a couple of peaks on the western section of the rim reaching heights of around 4.5km. The rim looks fairly continuous except when the Sun angle is low. At such times, the southeast section appears less distinct, almost smoothed over. One theory suggests that this is because the material here has collapsed into the centre of the crater, forming a smoother landscape leading down to Piccolomini's floor.

Most of the inner rim is heavily terraced, leading down to what appears to be a relatively smooth floor surface. The terraces encroach furthest toward the centre of the crater in the southern half, possibly something to do with the section of Rupes Altai which would have been here when Piccolomini's impact hit. At the centre of the crater is a magnificent central mountain complex rising to a height of around 2.5km. There is a small 3.5km craterlet located to the north of the central mountains, a good test for an 8-inch or larger telescope.

The area immediately north of Piccolomini appears as a pentagonal pattern of smaller craters, hexagonal if you include the smaller 12km craterlet to the north, Piccolomini B. Most distinctive is 23km Piccolomini M which appears to touch the northern edge of its primary crater. Northeast is 17km Piccolomini D, then 18km E. B lies to the west-northwest of E, with overlapping 16km A and 11km O to the south-southwest of B. Looking far less distinct is 26km C between O and M, a much more eroded crater in comparison to the others. In the centre of the pentagon is 8km X, another eroded craterlet which can be hard to see when the sun-angle is high. X sits within the much harder to see 71km F, a heavily eroded outline which also encompasses E and D.

To the west lies 41km **Rothmann**, another prominent crater with complex and wide inner terraces. These lead to a small flat floor area with an off-centred, twin-peaked mountain complex. 45km **Stiborius** lies to Piccolomini's south and isn't dissimilar in appearance to Rothmann. A similar situation occurs to the east with 50km **Neander**, although this crater is defined by 11km Neander A positioned inside the northwest rim wall of its primary.

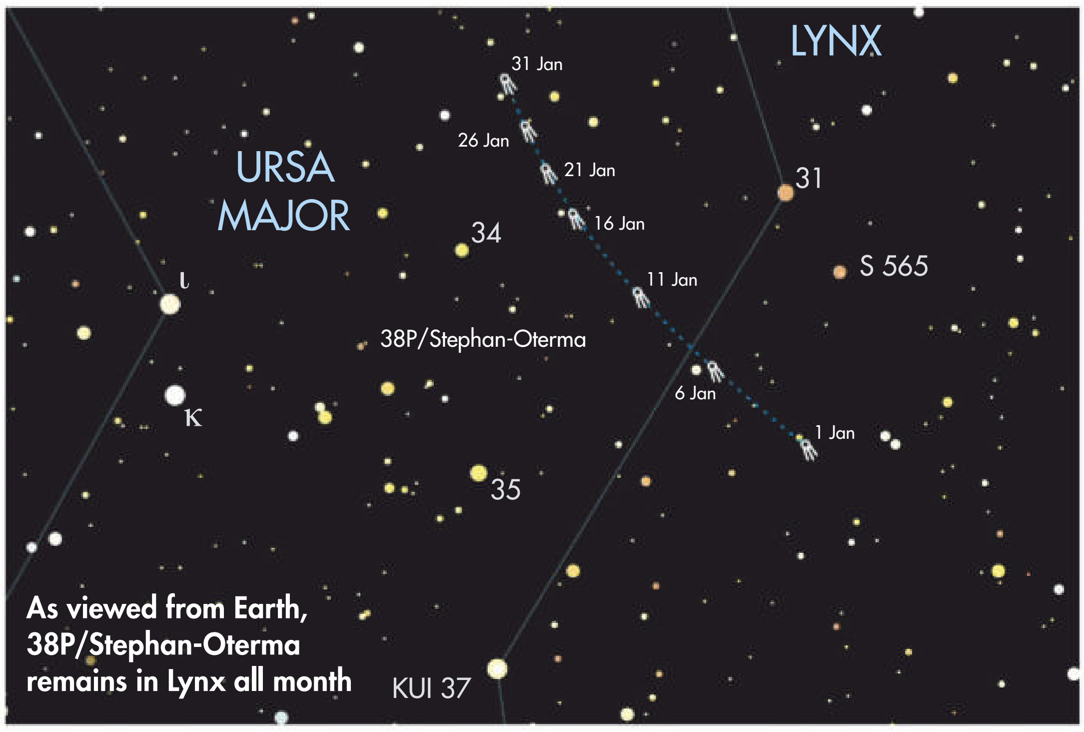
The most prominent neighbour is the impressive walled plain of **Fracastorius**, 260km north of Piccolomini. Fracastorius is located on the southern edge of Mare Nectaris and has become flooded with lava from the mare, the northern section of the crater being absent from view. The location of Fracastorius means that when the terminator is close enough to show it off at its best, Piccolomini will be optimally illuminated too.



IMAGES: PETE LAWRENCE X 4

COMETS AND ASTEROIDS

Comet 38P/Stephan-Oterma's slow apparent motion in January is handy for imagers



As viewed from Earth, 38P/Stephan-Oterma remains in Lynx all month

Comet 38P/Stephan-Oterma has been gracing the night sky for a while now, but has been overshadowed by the prospect of 46P/Wirtanen reaching naked eye status. Ironically, both comets ended up in the indistinct constellation of Lynx at the end of December and that's where we pick up the path of 38P during January.

At 00:00 UT on New Year's Day the 10th magnitude comet can be found 4° southeast of mag. +4.2 31 Lynxis. It then travels north, veering slightly northwest towards the end of the month when it will have dimmed to mag. +11.6. Thanks to its late course correction, 38P remains within the boundaries of Lynx all month long. Travelling a relatively small distance through the month, 38P is well suited to astrophotography, its relatively slow motion amongst the stars helping to avoid motion blur during a 1-2 minute exposure.

Comet 38P/Stephan-Oterma was first sighted by Jérôme Eugène Coggia in Marseilles, France on 22 January 1867. However, he quickly lost sight of his 'uncatalogued nebula' when clouds drifted in. It wasn't until the night of 24 January that EJM Stephan, also in Marseilles, was able to see the object again. He determined that it had moved and recognised it as a comet. Its second name was provided by Liisi Oterma from Turku, Finland who recovered the comet in November 1942.

38P/Stephan-Oterma is a Halley-type comet with an orbital period of 37.7 years and an aphelion distance of 20.9 AU. Halley-type comets have eccentric orbits, with periods ranging from 20 to 200 years. Over the years 38P has had numerous close passes of main planets. At the end of November 1866, weeks before its discovery, it passed Earth by 0.92 AU. In December 1942 it came as close as 0.63 AU, then on 9 December 1980 just 0.59 AU. Last month, on 17 December, it passed Earth by 0.77 AU.

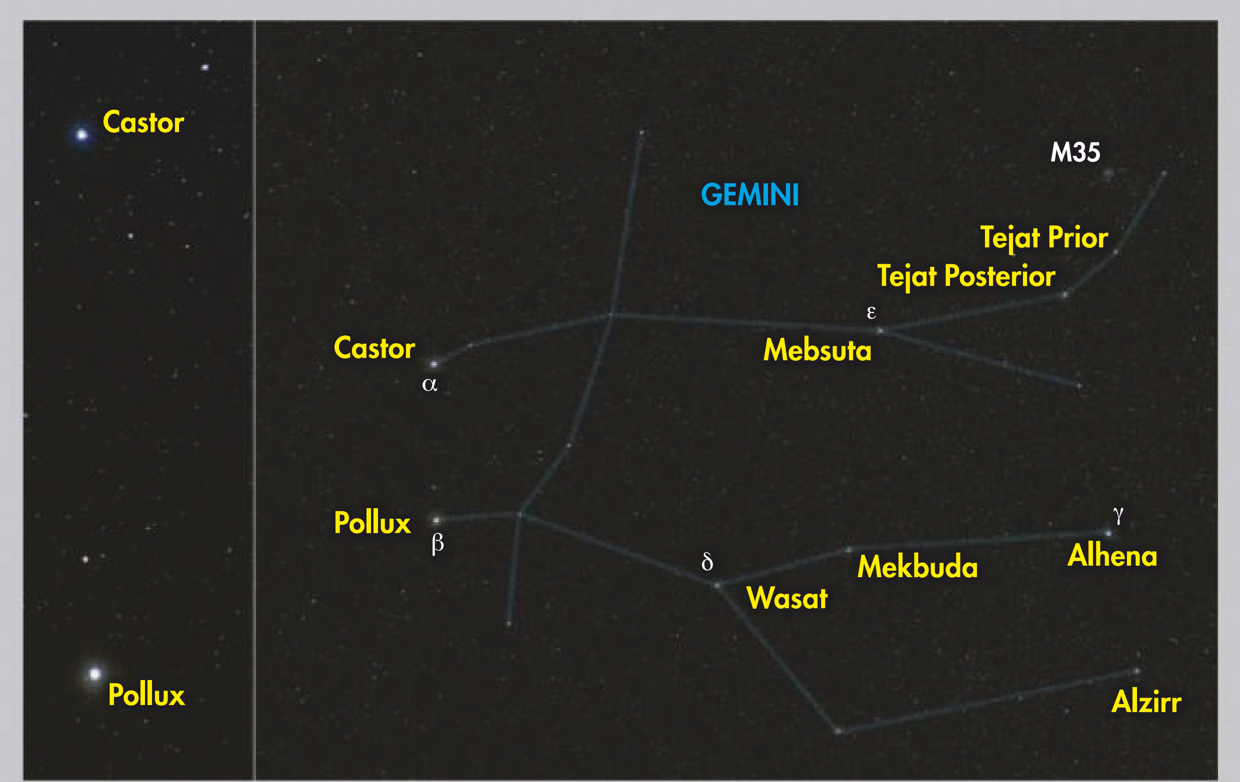
STAR OF THE MONTH

Pollux, one of the celestial twin stars in Gemini

Despite its beta status, mag. +1.2 Pollux (Beta (β) Geminorum) is the brightest star in Gemini and the 17th brightest star in the night sky. It is linked to mag. +1.6 Castor (Alpha (α) Geminorum) through mythology rather than any physical association. The stars provide the heads of the twins Castor and Pollux, who together form the constellation of Gemini. Castor lies at a distance of 51 lightyears while Pollux is closer at 33.8 lightyears.

On first appearance Castor and Pollux look fairly similar. It's only on close inspection that it's obvious that Pollux is brighter and shows a more orange-hued colour than its mythological twin. Pollux is an old giant star, the closest star of this type to our own Sun. It's around twice as massive as the Sun and about nine times its radius.

It is known to have a gas planet in orbit around it with an estimated mass of 2.3 Jupiters. Known as Pollux b, it has a nearly circular orbit of radius 1.64 AU, taking 1.6 years to complete one circuit around Pollux.



► The close-up image (left) reveals the colour difference between Gemini's most famous stars

The IAU's official name for Pollux b is Thestias, bestowed on it by public nomination in 2015.

Pollux has a spectral type of K0 III. The K0 part describes its position within the Morgan-Keenan spectral classification system. This is an important position because Pollux is regarded as one of the system's 'anchor' stars: a star that has a key spectral type which hasn't changed over the years. The 'III' identifies Pollux as a normal giant. Pollux has a weak X-ray emission similar to that of our Sun. Its magnetic field is particularly weak, with a strength measured below 1 Gauss, one of the weakest magnetic fields ever detected around a star.

The colour difference between Castor and Pollux is obvious and an interesting subject to reveal photographically. A particularly good way to do this is to capture both stars in one frame at long exposure so that they trail. This really emphasises their difference.

STEPHEN TONKIN'S

BINOCULAR **TOUR**

There's a dwarf planet to look out for this month as well as a wide spectrum of stars

☑ Tick the box when you've seen each one

1. NGC 2017

10x50 Begin by familiarising yourself with the brighter stars of Lepus, then identify Arneb (Alpha (α) Leporis). 1.5° due east of Arneb is a tiny group of stars, the brightest of which shines at mag. +6.4. This is NGC 2017. The NGC describes it as an open cluster, but it is really just a multiple star. How many stars you see will depend on your sky conditions: good conditions yielding will yield a row of three stars and an orange fourth just north of the row in 10x50 binoculars. This is a chance line-of-sight group, with actual distances ranging from 500 to 3,000 lightyears. ☐ **SEEN IT**

2. IOTA AND RX LEPORIS

10x50 Nearly 4° south of Rigel (Beta (β) Orionis) lies Iota (ι) Leporis, itself a fairly unremarkable mag. +4.5 brilliant white star, but it contrasts beautifully with the fainter reddish star, RX Leporis, which lies 0.25° to the west of it. RX Lep is slightly variable, oscillating between magnitudes +5.4 and +4.9 over a period of 74.5 days, but this main period is overlain by longer periods and it is classified as an 'unsolved' semi-regular variable. While you are here, scan around it: Iota and RX Lep are part of a rewarding, colourful star-field that fills the field of view of your binoculars. ☐ **SEEN IT**

3. THE STREAM

10x50 While we're looking at starfields, let's pan 6° west from Mu (μ) Leporis, where you will find the most northerly of a colourful string of mostly 5th and 6th magnitude stars running down to the southwest. There is a colour gradation from orange 60 Eridani at the top of the chain, through yellow 59 and 58, down to a fainter white star. Then it all changes with the reddish 54 Eri, the brightest star of the group. On a transparent night, see how many fainter stars you can see, especially near the top of the chain. ☐ **SEEN IT**

4. 62 ERIDANI

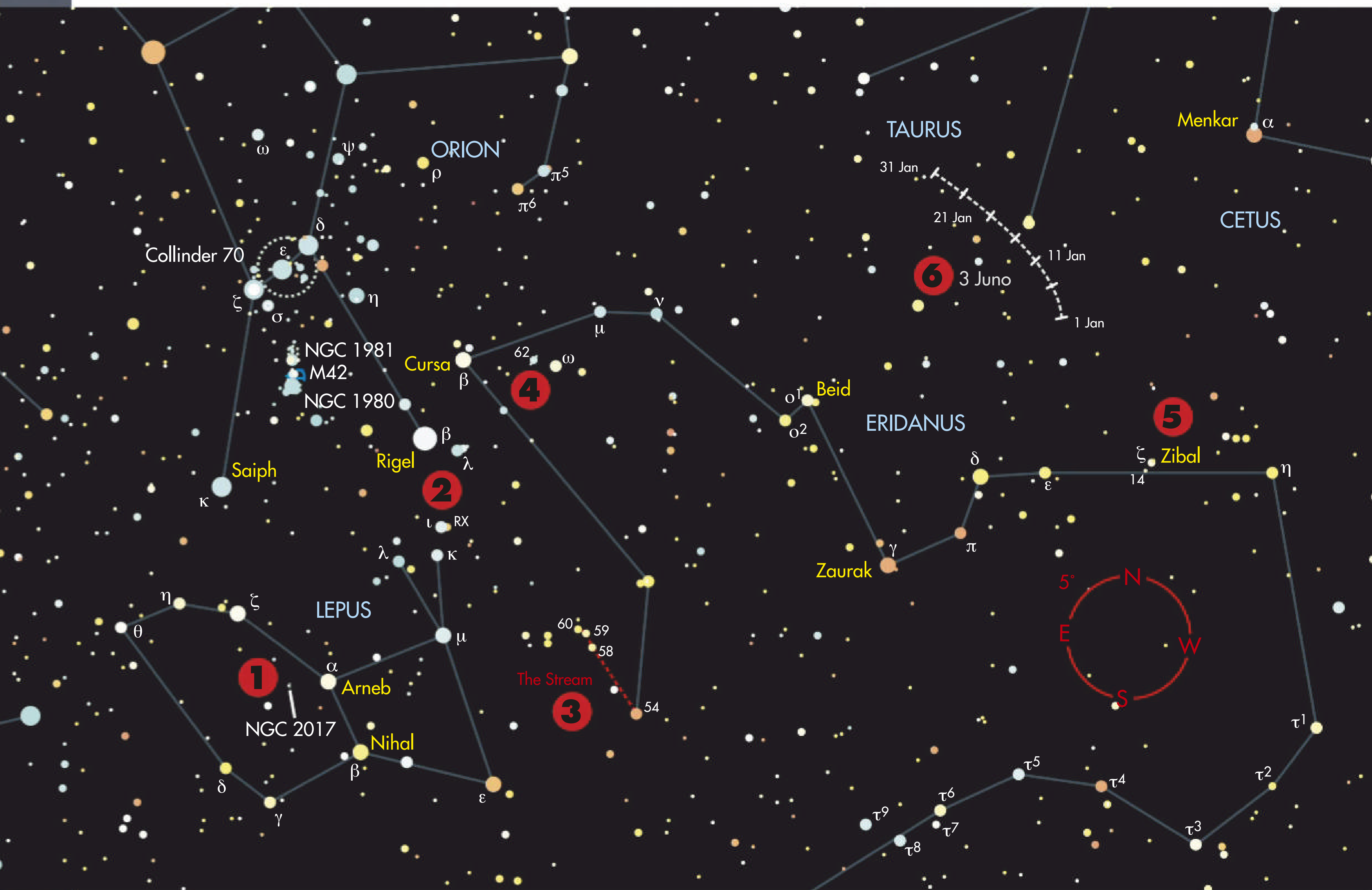
15x70 Go back to Rigel and identify Cursa (Beta (β) Eridani), 3.5° to its northwest. Linger around Cursa for a while and take time to appreciate its rich stellar environment before heading 3° due west to the brilliant blue-white mag. +5.5 62 Eridani. This can be a tricky double star, not because of the separation, which is a substantial 66 arcseconds, but because the companion is so much fainter (mag. +8.9) than 62 Eri. This is not a binary star, but an optical double: the fainter of the pair is four times further away than the primary. ☐ **SEEN IT**

5. ZIBAL

10x50 The mag. +4.8 Zibal (Zeta (ζ) Eridani) might just be visible to your naked eye if your southern aspect is good. It is part of a wide pair, the other member being 14 Eridani (mag. +6.1), which is 0.5° southeast. The 'pairing' does not end there; on the northwest of Zibal, a mere 5 arcminutes away, is another companion, shining at mag. +6.6. Both of these companions are line-of-sight associations, although Zibal is part of a binary system, but one that requires spectroscopy to detect; the secondary has an orbital period of only 17.9 days. ☐ **SEEN IT**

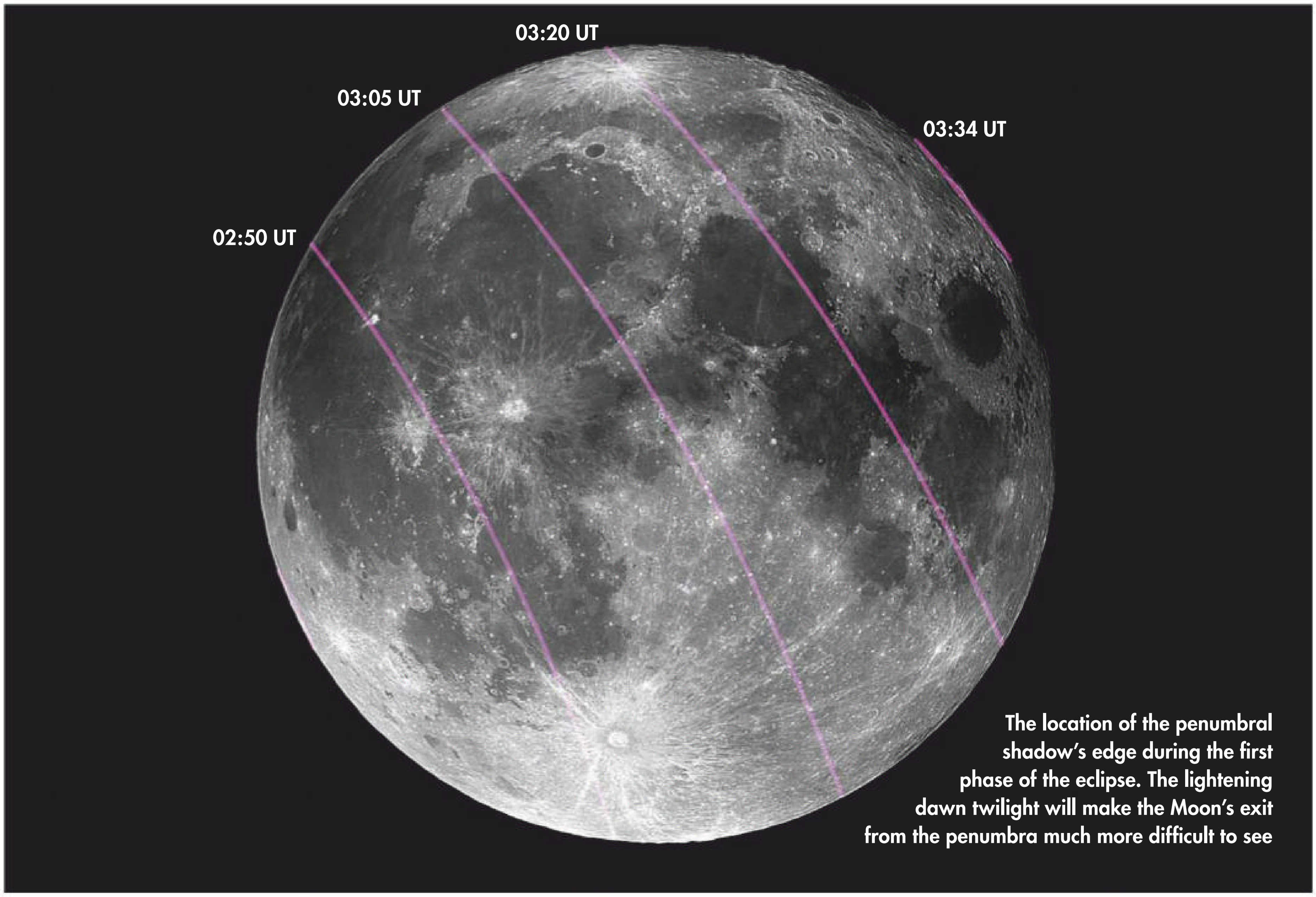
6. JUNO

15x70 Although only the 10th largest asteroid, Juno was the third to be discovered, thanks to its unusually high albedo, and this is what will enable us to continue observing it two months after opposition. Identifying it will be a bit of a challenge, so familiarise yourself with its region of sky, and note which 'star' has moved after a couple of days. At the beginning of January, it is mag. +8.2, so well within range of 15x70 binoculars, but see how long you can continue to observe it before it fades from view. ☐ **SEEN IT**



THE SKY GUIDE CHALLENGE

Will you be able to spot the less showy penumbral portion of January's lunar eclipse?



The location of the penumbral shadow's edge during the first phase of the eclipse. The lightening dawn twilight will make the Moon's exit from the penumbra much more difficult to see

The total lunar eclipse in the early hours of 21 January is really something to look forward to if the sky remains clear. The visual eclipse – the part which involves the Earth's dark umbral shadow – starts at 03:34 UT and runs until 06:51 UT. However, the true eclipse is longer than this because Earth's shadow extends beyond just the dark inner umbra. Our first challenge for 2019 is to see how early you can detect the passage of the outer, or penumbral, shadow across the Moon's disc.

In space, Earth's shadow looks a bit like the central bullseye on a dart board. If you flew a spacecraft to the distance of the Moon and moved into the inner umbra, the Sun would be completely hidden from view behind Earth's disc. Flying into the weaker penumbra surrounding the umbra and you'd see that only part of the Sun was hidden from view by Earth – basically a partial eclipse of the Sun.

The penumbra isn't uniform and gets concentrically darker the closer you are to the umbra. Thinking of that spacecraft view again, at the outer edge of the penumbra only a small portion of the Sun's disc would be obscured by Earth. Move in towards the umbra, and more and more of the Sun would be covered, meaning less light and a darker shadow.

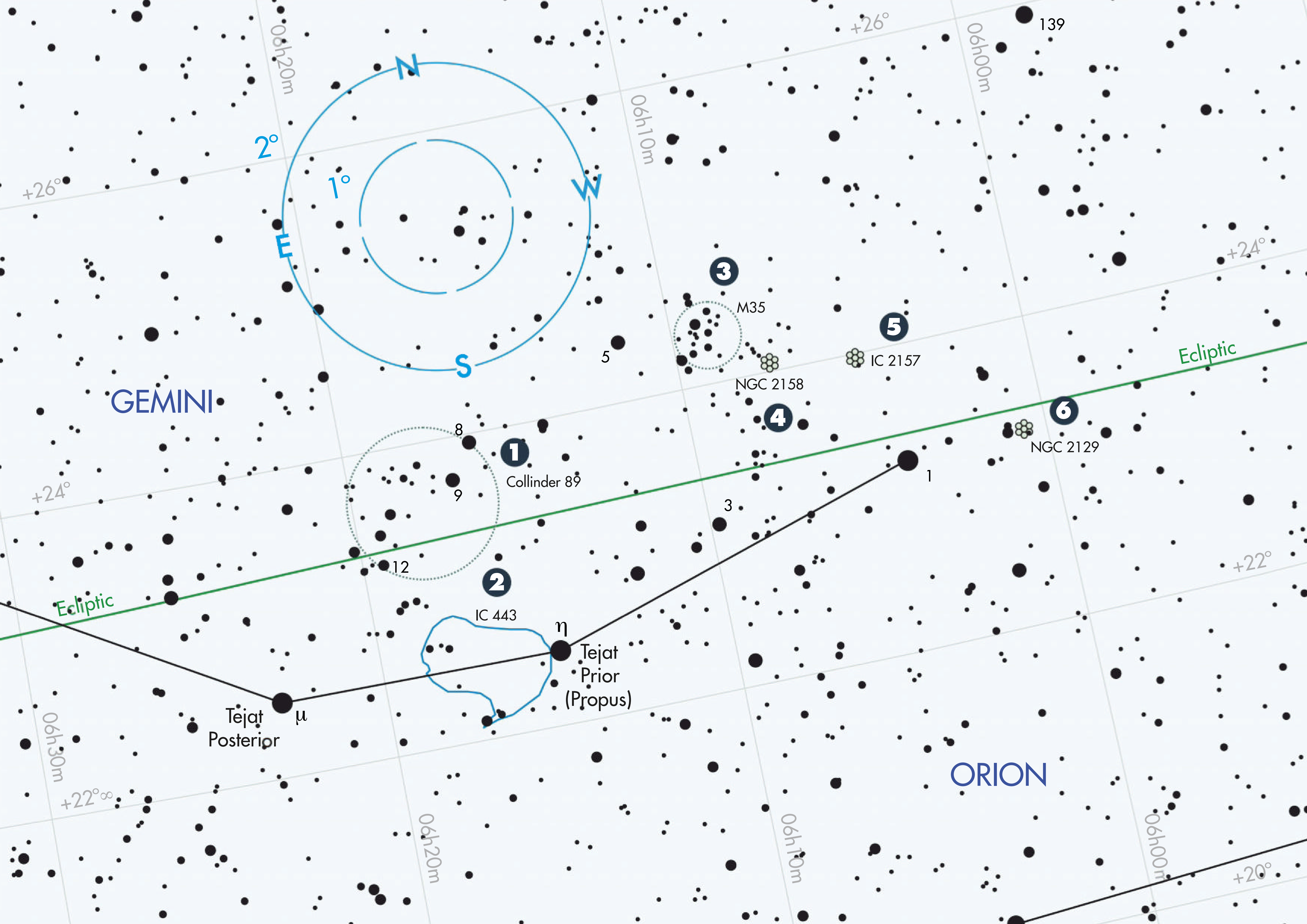
One problem with spotting the penumbra is that there is no distinct edge to it. The penumbral shadow first makes contact with the Moon at 02:37 UT but it's just too weak to see. Its effects can definitely be seen just before the umbral shadow first makes contact at 03:34 UT. Again, it doesn't have a distinct edge but rather appears as darker shading towards the Moon's western (left) edge. What tends to happen is the large, dark lava basins appear darker than usual.

Our challenge is to observe the Moon from 02:37 UT to 03:34 UT making a note of when you think you can see a real difference in its appearance. Visually this will be a difficult but useful exercise. Some lunar eclipses are purely penumbral, the Moon moving either too far north or south of the umbra for a full-blown lunar eclipse to take place. Once you've seen the penumbral portion of this eclipse it'll make future identification very much easier.

Photographically, the best strategy is to image the Moon's full disc over the entire penumbral eclipse period, creating a time-lapse animation with an interval separation of, say, five minutes between frames. Comparing the first image to the last will show the penumbral shadow easily. However, try comparing the first image to subsequently later shots to see at which point the penumbral shadow's presence can be seen.

▲ The subtle nature of a penumbral shadow crossing is evident from the darkening of the western lunar maria in this image

IMAGES: PETE LAWRENCE X 3


GEMINI
ORION
Ecliptic
Ecliptic
M35
NGC 2158
IC 2157
NGC 2129
Collinder 89
IC 443
Tejat Prior (Propus)
η
Tejat Posterior
μ
139
1
3
5
8
9
12
1
2
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4
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E
S
W
1°
2°
06h00m
06h10m
06h20m
06h30m
+20°
+22°
+24°
+26°

DEEP-SKY TOUR

A series of objects that get smaller but more intense around the foot of Castor

☑ Tick the box when you've seen each one

1 COLLINDER 89

This month's Deep Sky Tour is based around the foot of the twin Castor in Gemini. This is marked by a distinctive curved line of stars including Tejat Posterior (Mu (μ) Geminorum), Tejat Prior (Eta (η) Geminorum) and 1 Geminorum. Balanced on Castor's foot are numerous open clusters the largest of which, on paper at least, is Collinder 89. This has a visual magnitude of +5.7 but is large, sparse and best seen with a telescope using a low magnification, wide-field eyepiece. Even then it's easy to overlook because it lacks any real concentration. It runs between mag. +6.1 8 Geminorum and mag. +7.0 12 Geminorum and has a line of 7th magnitude stars crossing its centre. The Milky Way runs through this region providing a rich background of faint stars. ☐ **SEEN IT**

2 IC 443

If you imagine a line joining Mu and Eta Geminorum, our next target, the supernova remnant IC 443, occupies the half of that line closest to Eta. IC 443 is also known as the Jellyfish Nebula because of its resemblance to a swimming jellyfish in long-exposure photographs. Visually, the object is quite challenging and requires the use of an 8-inch or larger scope with visual assist filters such as OIII and UHC to see convincingly. A good, dark sky is also highly recommended. Even then, it's only the brighter portion that is visible, the arcing glow that occupies the northeast portion of the nebula. Through the eyepiece this appears like a faint glowing arc of light approximately 20 arcminutes in length. Larger instruments show the glow to be knotted in appearance. ☐ **SEEN IT**

3 M35

We mentioned how large Collinder 89 looks on charts and how sparse it looks through an eyepiece. Our next target, M35, looks smaller on charts but is far more impressive through a telescope. It marks the north-pointing right angle in a triangle formed with Eta and 1 Geminorum. At mag. +5.3 it's visible to the naked eye as a faint smudge. M35 occupies an area around 0.5° across and contains upward of 500 members, about 120 being brighter than mag. +13. A number of orange stars contrast beautifully with the general blue-white colour of the majority. Numerous star arcs can also be seen. A particularly nice asterism in the cluster resembles the outline of the space-shuttle coming in to land. ☐ **SEEN IT**

4 NGC 2158

Continuing the trend of reducing chart sizes and increasing concentration brings us to our next target on this tour, the open cluster NGC 2158. This is easy to find, sitting 24 arcminutes southwest of the centre of M35. At mag. +8.5 it's a lot fainter than its visually splendid sky neighbour but equally, it's more concentrated. NGC 2158 is also considerably smaller than M35, roughly a sixth of the size at 5 arcminutes across. The cluster is best viewed with larger instruments as its surface brightness is quite low. Even low light pollution hides it from view. However, under dark skies it is possible to see NGC 2158 surprisingly well even with an 3-inch refractor. The cluster's dimness and small apparent size comes from the fact that it's around 11,000 lightyears away. M35 for comparison is 2,800 lightyears from the Sun. ☐ **SEEN IT**

◂ **IC 443, also known as the Jellyfish Nebula, is a supernova remnant that is roughly 5,000 lightyears from Earth**

THIS DEEP-SKY TOUR HAS BEEN AUTOMATED

ASCOM-enabled Go-To mounts can now take you to this month's targets at the touch of a button, with our Deep-Sky Tour file for the EQTOUR app. Find it online.

5 IC 2157

Next we travel to another open cluster close to the southern end of Castor's foot. IC 2157 is located 35 arcminutes to the west of NGC 2158 and 46 arcminutes north of 1 Geminorum. This object is visible in a small scope as a faint, round glow with several brighter stars overlaid across it. Like Collinder 89, IC 2157 can appear quite sparse through the eyepiece, an attribute not helped by the fact it's set against a rich background of Milky Way stars. A 10-inch scope shows its ill-defined nature well, revealing around 15 stars in a 5 arcminute area, which is a similar size to NGC 2158. The brightest members are around mag. +10.5. ☐ **SEEN IT**

6 NGC 2129

Our final object this month is another open cluster in Gemini. This is mag. +6.7 NGC 2129 which lies 43 arcminutes to the west of the mag. +4.2 1 Geminorum, the star marking Castor's toe. Incidentally, 1 Geminorum is notable because it is occulted by the Sun at the June solstice. Consequently it marks the approximate location of the most northern part of the ecliptic. The cluster is visible but unremarkable in a small telescope, showing two bright stars of magnitudes +7.4 and +8.2 aligned north-south. A 10-inch scope reveals over 30 stars in a 5 arcminute area with subtle concentration. The two brighter stars are HD 250289 to the north and HD 250290 to the south. They share similar proper motions, suggesting they may be part of a binary system. ☐ **SEEN IT**

YOUR BONUS CONTENT

Print out this chart and take an automated Go-To tour

CHART: PETE LAWRENCE, PHOTO: MANFRED WASSHUBER/CCDGUIDE.COM

ASTRO**PHOTOGRAPHY**

▲ Capturing the Moon mid-lunar eclipse will challenge your mastery of exposures

Photographing a lunar eclipse

RECOMMENDED EQUIPMENT

DSLR camera, 200mm or longer focal length lens, or a telescope

THE BIG PICTURE

A LUNAR ECLIPSE THAT WILL PLAY OUT IN ITS ENTIRETY OVER THE UK

A total lunar eclipse will occur in the early hours of 21 January 2019. From the UK the entire event will be visible, with the latter stages starting to become affected by the onset of dawn. A lunar eclipse is a relaxed affair, taking several hours to play out in full. As far as imaging is concerned the most important consideration is how you intend to capture it. Do you want to get a large image of the Moon's eclipsed disc or are you after a wide-field sequence showing how the eclipse plays out? Whichever you choose, it pays to be prepared well in advance.

ALL PICTURES: PETE LAWRENCE

The total lunar eclipse on 21 January is well placed for UK viewing. Our last one, on 27 July 2018, was a damp squib. After days of cloudless summer skies, the weather closed in just in time to ruin the event, obscuring it from virtually all of the UK. Even if we could have seen it, we'd only have enjoyed part of the spectacle; totality was already underway even before the Moon rose over the horizon. Fortunately the 21 January eclipse will take place entirely in UK skies so all we have to hope for are no clouds.

The eclipse starts at 02:37 UT when the Moon's disc enters the weak outer penumbral shadow. This month's Sky Guide Challenge (on page 61) is to see how early on you can determine the effects of the penumbral shadow. Photographically, this shouldn't be too difficult as long as exposures and settings are maintained. It's important to ensure that any image of the Moon's disc is correctly exposed. A low ISO and short exposure should cope well with this bright Moon. Comparing images taken at, say, five-minute intervals should reveal the subtle advance.

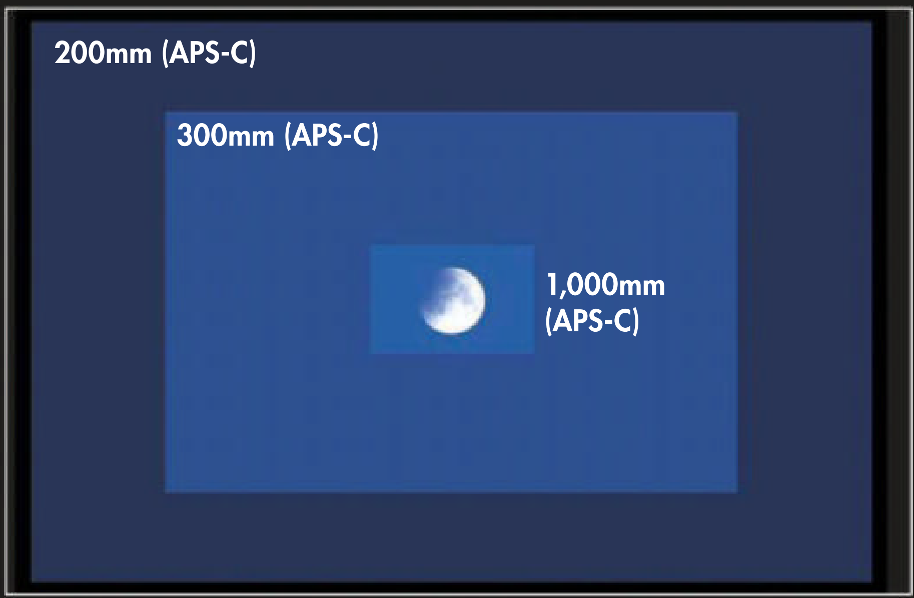
The main visual part of the eclipse occurs when the Moon enters the darker umbral shadow. This starts at 03:34 UT and continues until 06:51 UT. The period of totality – when the umbral shadow fully covers the Moon's disc – is between 04:41 UT and 05:43 UT. Totality is somewhat easier to deal with than the two partial eclipses either side of it. A partially eclipsed Moon presents part of the Moon's disc darkened by the umbral shadow and part at normal brightness. A typical DSLR doesn't cope well with this and you'll normally end up with shots that show either a black shadow with correctly exposed bright surface or a white surface with a beautifully coloured eclipse shadow.

Depending on your exposure frequency – ie, one shot every two minutes – it's possible to jump between two camera settings to take alternate shots revealing either shadow or surface. A camera attached to a telescope works well if you're after lunar detail. A focal length around 1m provides a good balance between image scale and ease of tracking and framing.

Normal camera lenses can be used too. For reasonable disc detail, a 200mm or longer lens is recommended, but the essence of the eclipse can still be achieved with shorter lenses. Using a wide-angle lens it's possible to produce a sequence shot showing the Moon's brightness changing over time. For this eclipse we recommend a 15mm focal length for a non-full-frame or 25mm for a full-frame DSLR. Mount the camera on a fixed tripod pointing at azimuth 255° (position Betelgeuse on the frame's vertical centre line at 02:34 UT). Adjust so the horizon runs along the bottom (long) edge of the frame and ensure the Moon's in the image. Take shots at intervals of two to three minutes and add the images in a layer-based editor with upper layer blend modes set to Lighten. The initial images of the Moon's disc will typically need to show it over-exposed to white to cope with the dimming that occurs during the main part of the eclipse.

✉ Send your images to: hotshots@skyatnightmagazine.com

STEP BY STEP



STEP 1

Select a lens or telescope to give you the field of view you need for the type of image you are after. A 1m focal length gives good close-up detail but tracking is recommended at such a scale. A 200mm lens will show the Moon's disc with the eclipse shadow. A wide-angle lens (see opposite) can be used to generate a sequence composite.

STEP 2

If you're using just a camera set it to [M]anual focusing, with an ISO of 200-400 and aperture of f/8–f/11. Pre-focus using the full Moon just before the eclipse starts. RAW format will produce the best results. If you're not sure how to use RAW, capture as RAW + large JPEG. This will give you something to work with (JPEG) until you get used to RAW.

STEP 3

The following steps assume the use of a camera attached to a telescope. As in step 2, pre-focus the scope on the Moon before the eclipse. The Moon's edge is the best target for this. It's a good strategy to check the focus at regular intervals throughout the event, although this can be hard to do during the period of totality if the Moon is especially dark.

STEP 4

Exposures depend on your setup and the darkness of the eclipse. Totality can range from light coppery-yellow to deep brown, so dark the Moon's disc virtually disappears. Pre-eclipse, expose correctly for the Moon's surface and make a note of the settings. This will give you the settings for a correctly exposed surface with a virtually black shadow.

STEP 5

To show colour and detail within the umbral shadow you'll need more light sensitivity. Consider lowering the f/number, increasing the ISO to a mid-range value and increasing exposure time, in that order. Once you're happy with the detail you're imaging, make a note of the setting so you can return to it if you later decide to experiment further.

STEP 6

During totality consider taking a shot with the Moon centered in frame using increased sensitivity to push the eclipsed Moon towards over-exposure. This should reveal background stars. A normal eclipse image and this 'star' shot can be combined using a layer-mask to produce a beautiful composite showing the eclipsed Moon against a star field.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Our Solar System's most peripheral planets all have mysteries that amateur observations can help to solve

IMAGING FOR SCIENCE

Part 9: Mercury, Venus, Saturn, Uranus & Neptune

Our ongoing guide to giving your astrophotos scientific value continues with a look at some of the more difficult-to-capture planets at the extreme inner and outer edges of the Solar System

For this instalment of Imaging for Science we are looking at five planets that give a somewhat lesser return for amateurs than Mars and Jupiter. That's not to say that observations or images of these worlds are any less important, it's simply that getting decent results from Mercury, Venus, Saturn, Uranus and Neptune can be quite challenging.

For example, in the case of Saturn, its greater distance and more subdued appearance lessens the detail that can be recorded compared to its inner neighbour Jupiter. But with care and dedication, each of these worlds has the potential to supply a lifetime of interesting results.

In many ways, advances in amateur imaging have opened up new territory that wasn't possible to explore a few years ago. The use of specialist filters has played a major part here, allowing more detail to be extracted as well as providing higher contrast views under certain conditions, such as in daylight for the inner planets, Mercury and Venus.

ABOUT THE WRITER

Sky at Night presenter Pete Lawrence is an astrophotographer with a particular interest in digital imaging

▲ Planets Mercury, Venus, Saturn, Uranus and Neptune may not show the dramatic changes evident with Mars and Jupiter, but careful and methodical imaging will still reveal subtle changes that are just as scientifically relevant

Hardware & software

HARDWARE

- **High-frame-rate cameras**
- **RGB imaging filters for use with a mono camera**
- **Speciality filters, eg, longpass**
- **Filter wheel**
- **Atmospheric dispersion corrector**
- **Large-aperture, long-focal-length telescope on a driven mount**
- **A laptop**

SOFTWARE

- **WinJUPOS (freeware available from jupos.privat.t-online.de/index.htm)**
- **Capture software, eg, FireCapture (freeware, www.firecapture.de) or SharpCap (freeware and commercial, www.sharpcap.co.uk)**
- **RegiStax (freeware, www.astronomie.be/registax)**
- **AutoStakkert! (freeware, www.autostakkert.com)**
- **Image editor, eg, GIMP (freeware, www.gimp.org) or Photoshop (commercial, www.adobe.com/uk/products/photoshop.html)**

PETE LAWRENCE X 4

Submit your pictures for science

"Mercury, Venus, Saturn, Uranus and Neptune are all fascinating worlds that require patience and dedication to observe and record," says Paul Abel, director of the Venus and Mercury section at the BAA. "Each has its own area of interest for imagers. For example, Venus was long regarded as the planet of mystery, shrouded by thick clouds. Spacecraft have visited the planet, and although the results are useful, it is no substitute for long-term systematic observation of the planet.

"Visual observers can monitor the subtle cloud features from which we infer Venus's four-day atmospheric rotation. Venus shows phases as it moves around the Sun, but the theoretical phase differs from the observed phase because of the Schröter effect. Measuring the phase of Venus is useful work for visual observers.

"Imagers have taken up the challenge in recent years of producing stunning images of the planet in both infrared (IR) and ultraviolet (UV). In UV, the vague cloud markings are transformed into definite structures whose rotation can be measured. Other amateurs using IR have found hotspots on the night side of Venus – a clue, perhaps, that there may still be active volcanoes there.

"The BAA 'Mercury and Venus' and 'Saturn, Uranus and Neptune' sections can provide advice and assistance on observing these fascinating worlds and we welcome your observations regardless of your level of expertise."

Paul Abel, British Astronomical Association

PROJECT 1

Imaging MERCURY AND VENUS

Using filters reveals the subtleties in the Solar System's innermost planets

The inferior planets Mercury and Venus both exhibit phases. Because it's a rocky world, recording Mercury's phase reveals few surprises, but what's of more interest are images that show albedo variations on the planet's surface. This requires apertures larger than 8 inches (200mm) to achieve well. Images of Mercury are best made during daylight hours when the planet is highest above the horizon. Using a red or infrared filter helps to increase the planet's contrast, darkening the surrounding blue sky.

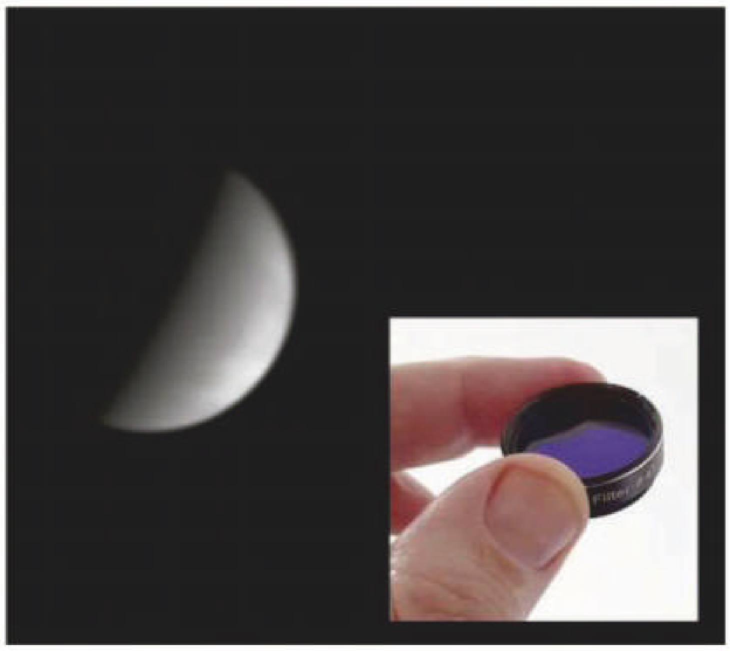
Venus has a dense atmosphere, and images showing its phase through different filters provide data that records the planet's phase anomaly. This is most evident around dichotomy when the planet should, mathematically at least, appear exactly half lit. In practice, the phase anomaly means that Venus reaches this phase early when it's visible in the evening sky and late when it's in the morning sky. The effect is believed to be related to how sunlight scatters in Venus's atmosphere.

The Venusian atmosphere can respond well to certain filters. Most variation tends to become evident through shorter wavelengths filters, in particular ultraviolet. Such filters can be expensive, although interesting imaging results have been obtained using visual purple filters (eg, Wratten #23A) fitted with an additional IR-blocking filter.

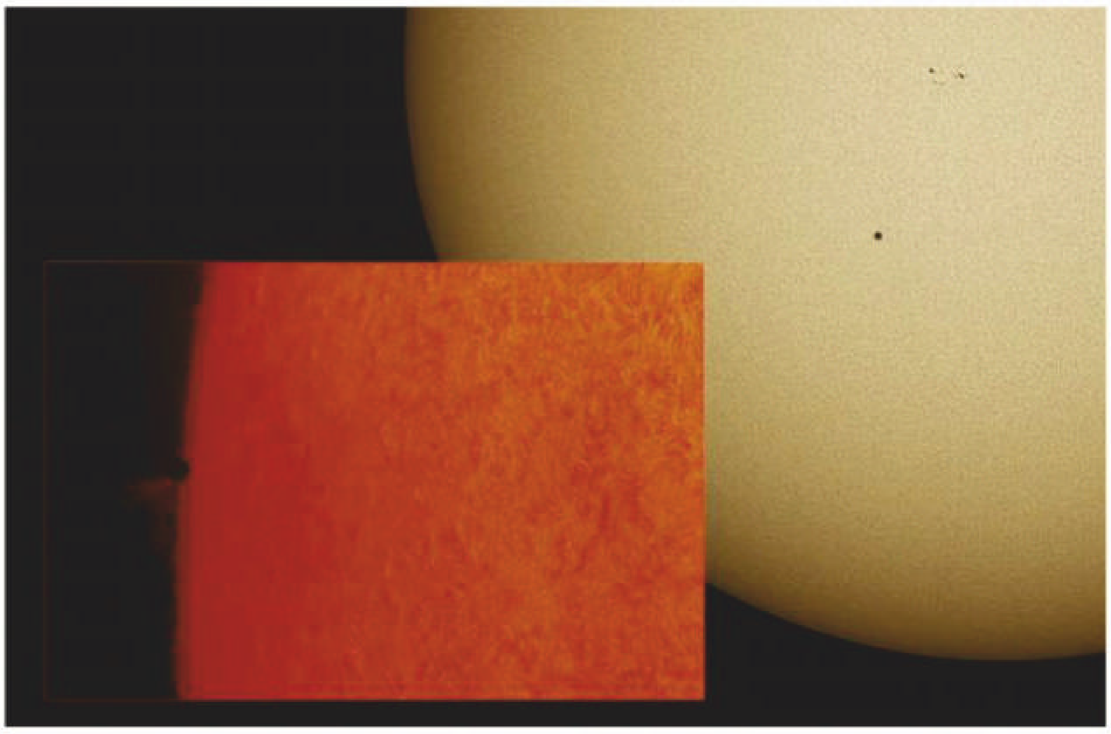
At the other end of the spectrum, near-infrared filters have been able to reveal the Venusian night-time hemisphere, typically when the planet appears as a thick crescent. When Venus is a thinner crescent, some people (including William Herschel and Patrick Moore) have claimed you can see a phenomenon known as the Ashen Light, which makes the dark portion of Venus's disc visible to the eye. Others, however, put these sightings down to observer error or equipment malfunction. To date, there have been no images to support visual reports of this effect. Could you be the first to capture proof of it?

Finally, although the next transit of Venus is not due until 2117, transits of Mercury are more common and timed images of such events are always useful. In particular timings through speciality filters, such as H-alpha, provide yet another dimension to this infrequent event.

◄ Two daytime captures of Mercury (top) compared with deliberately blurred simulated views from WinJUPOS (bottom) show some good similarities between features



▲ Venus's cloud features can be imaged using a visual Wratten #47 filter along with an infrared blocking filter



▼ Modern speciality filters, such as those used to view the Sun's H-alpha emissions, can produce new ways to view infrequent events such as the transit of Mercury

PROJECT 2

Imaging SATURN

Storms, colour variations and ring spokes are all worth tracking

Saturn is a major gas planet but the amount of detail it shows through amateur scopes is significantly less than its inner neighbour, Jupiter.

This is because of the high layer of haze in its atmosphere and its greater distance from the Sun. Consequently Saturn's atmospheric features are far more subtle in appearance. Bright spots on its disc represent the presence of Saturnian storms. Observing and recording such events is extremely important and programs such as WinJUPOS can be used to measure their position and track drift. Occasionally, larger long-lived events, such as the 'Dragon Storm' of 2010/11 (a large, bright and complex convective storm in Saturn's southern hemisphere), break out and appear to spread through many degrees of longitude. Frequent imaging is encouraged to help provide a global record of these infrequent events.

In addition to the appearance of storms in Saturn's atmosphere, the planet also shows a series of belts just like those seen in Jupiter's atmosphere. However, unlike the Jovian belts, Saturn's appear far less prominent and detailed. Despite this, images taken through different filters can provide important information as to how the intensity of the belts changes. When Saturn is presented with a high tilt angle, an interesting exercise is to try to record phenomena found at the polar regions, such as the northern hemisphere's polar hexagon. Between 2012 and 2016, the hexagon changed from mostly blue to more of a golden colour, so those this is definitely an interesting, dynamic feature for amateur astronomers to chronicle.

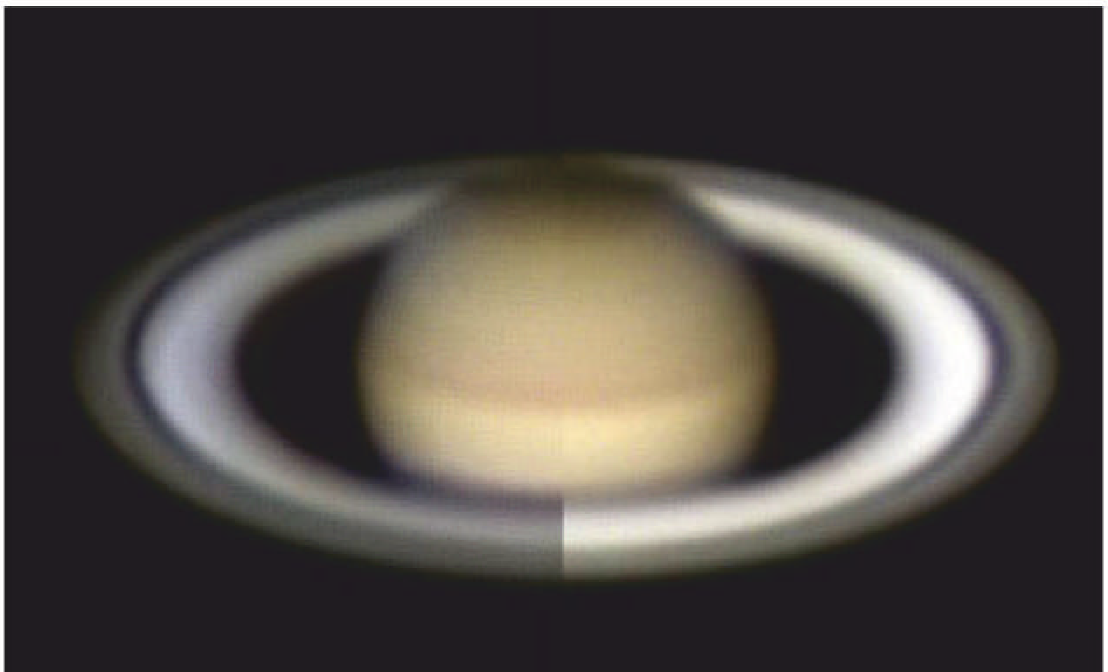
Of course, a major feature of this beautiful world are its magnificent rings and monitoring them for subtle variations in intensity is another important project for amateur imagers. The presence and appearance of radial 'ring spokes' is of particular interest. Imaged and animated by orbiting spacecraft, this phenomena has been reported by visual observers many times too. Capturing an animated sequence showing ring spoke movement from Earth would be a very valuable record indeed.

As with most planets, the use of filters can enhance the contrast of certain features. As ever, it's important to accurately record the date, time and which filters have been used to produce each image.

ALL PICTURES: PETE LAWRENCE

The use of imaging filters (a red one is being used here) can help improve the visibility of Saturnian phenomena such as the Northern Hemipshere's polar hexagon

Like Jupiter, Saturn's atmosphere shows numerous belts and zones. Recording variations in their intensity and colour will make valuable contributions to science



Saturn's rings appear brighter near to opposition than at other times, as this compare and contrast shows

PROJECT 3

Imaging URANUS AND NEPTUNE

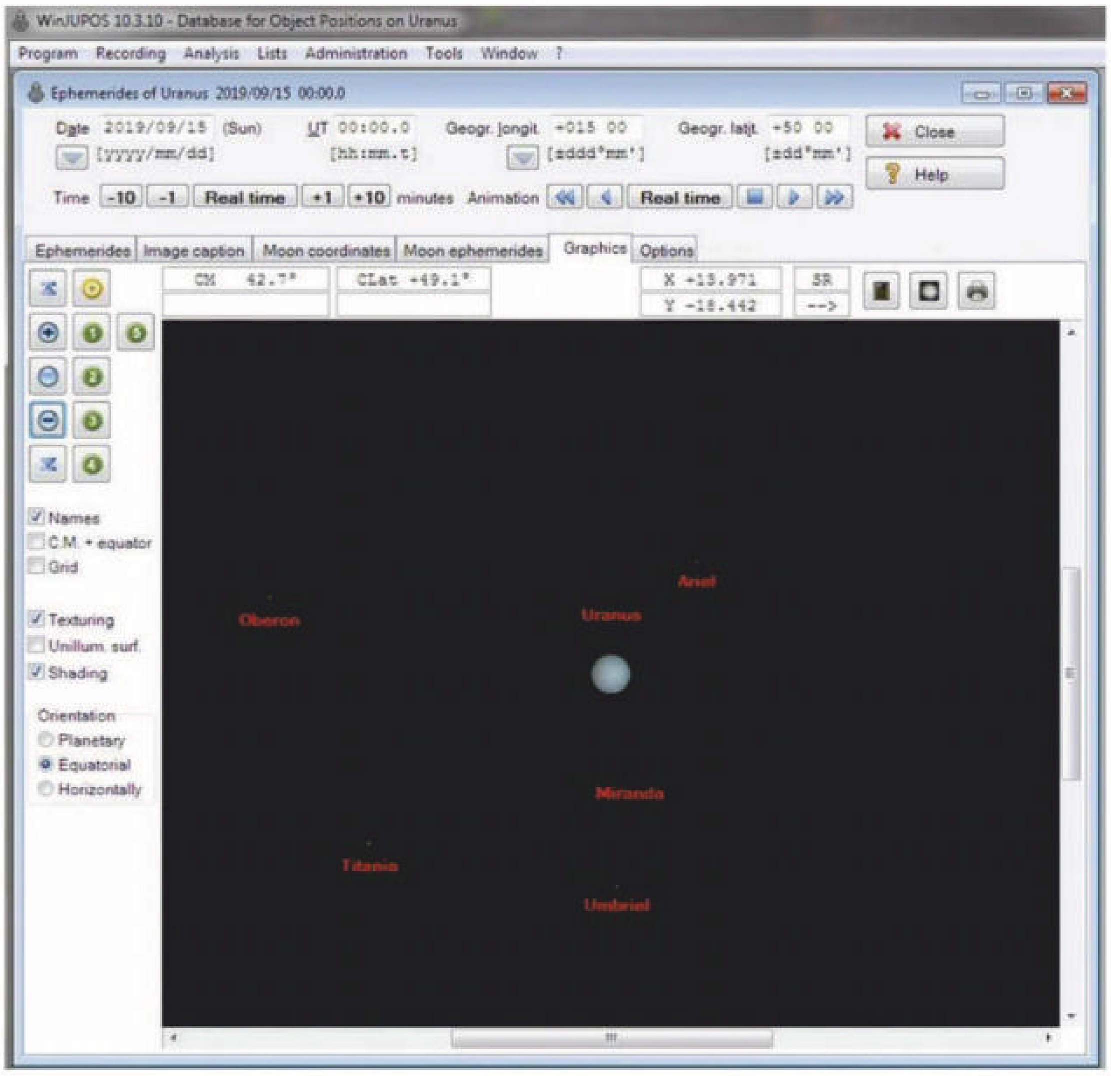
Large apertures and long capture times reveal the ice giants' secrets

They may be large bodies, but the ice giants Uranus and Neptune are also very distant and this makes them significantly more difficult to image usefully. Large apertures work best but the quality of the atmosphere you're imaging through also plays a very important part. With an apparent disc of typically just 3.7 arcseconds across for Uranus and 2.2 arcseconds for Neptune, it doesn't take much atmospheric unsteadiness to hide any detail in these far off planets.

Their great distance also makes them fairly dim for the process of high-frame-rate imaging. However, if your goal is just to capture any belts or bands visible on their globes, long capture times are perfectly acceptable as long as the technique is documented with the image. Capture times running to several tens of minutes are not uncommon. Upping the camera sensitivity and capturing frames at a relatively slow frame rate is a viable technique here. A useful tip for focusing is to image a nearby star before you start your capture run and pre-focus accurately on that. This assumes you can find the planet again after focusing has been completed!

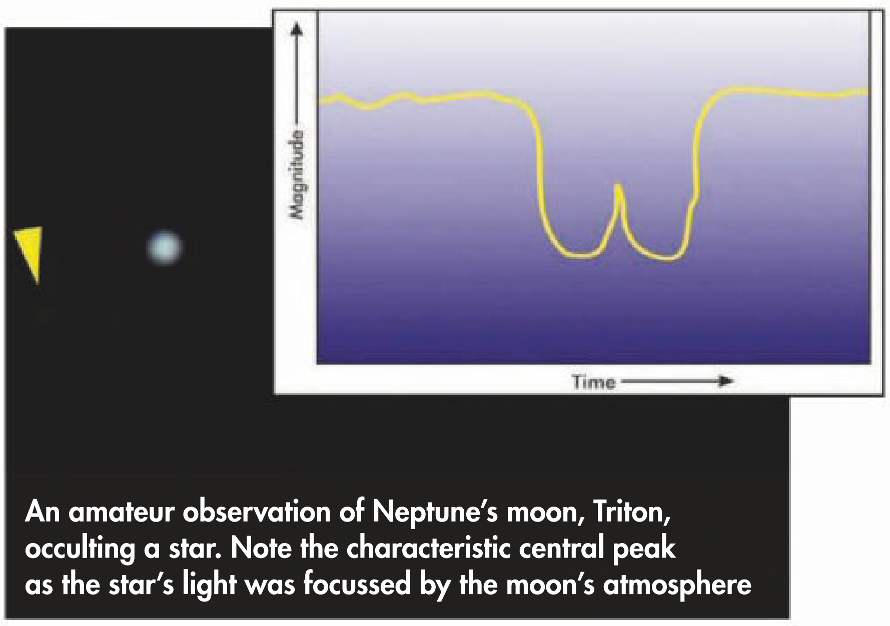
For Uranus, long-pass or infrared-pass filters tend to be the most useful, combined with a mono high-frame-rate camera or an IR-sensitive colour camera. A large aperture of at least 10 inches (250mm) is recommended, together with an R+IR filter. The Baader RG 610 delivers a relatively bright image for instruments at the smaller end of the recommended size range under average seeing conditions. For larger apertures above and including the 12- to 14-inch (300 to 350mm) size range, a Baader RG685 filter can be used under excellent seeing conditions.

Bright spots on the globes sometimes occur but the small disc sizes and unsteady atmospheric conditions sometimes make it hard to determine if they're real. In which case, make several captures separated by, say, 15 minute intervals. Processing the captures then turning them into an animation will help determine whether the spots are consistent, and therefore real.



▲ The freeware WinJUPOS can be used to provide important ephemeris and analysis tools when imaging both Uranus and Neptune

Uranus (left) and Neptune



An amateur observation of Neptune's moon, Triton, occulting a star. Note the characteristic central peak as the star's light was focussed by the moon's atmosphere

The imager's guide to CMOS deep-sky photography

With the popularity of CMOS cameras increasing, **Gary Palmer** reveals how they can be used on deep-sky objects as well as planets

ABOUT THE WRITER
Gary Palmer is an experienced astrophotographer and member of the British Astronomical Association

This image of the Andromeda Galaxy, M31, shows you the quality and detail that can be achieved with a CMOS camera

GARY PALMER

▲ **The CMOS camera used here was a ZWO ASI 094MC Pro with a Sony IMX094 CMOS sensor**

CMOS cameras have become more and more popular over the past few years. Having started out as high-speed planetary imaging cameras they're increasingly being used for deep-sky imaging by more and more amateurs. Now that they are becoming well established in that area we are seeing fully cooled cameras and full-frame sensors arriving on the market. The cost in some cases is a fraction of that of CCD cameras a few years ago and now respectable images can be produced using small cameras priced under £300. CMOS cameras have a lot of other benefits as well as price, such as short imaging times and the ability to capture without guiding on some imaging setups, thanks to the amount of detail that can be captured in a short exposure.

In this article we're going to run through how to capture and process a data set for M31, the Andromeda Galaxy, using a CMOS camera. This popular deep-sky object has lots of fine detail that can be revealed by following some basic steps and avoiding a number of common pitfalls.

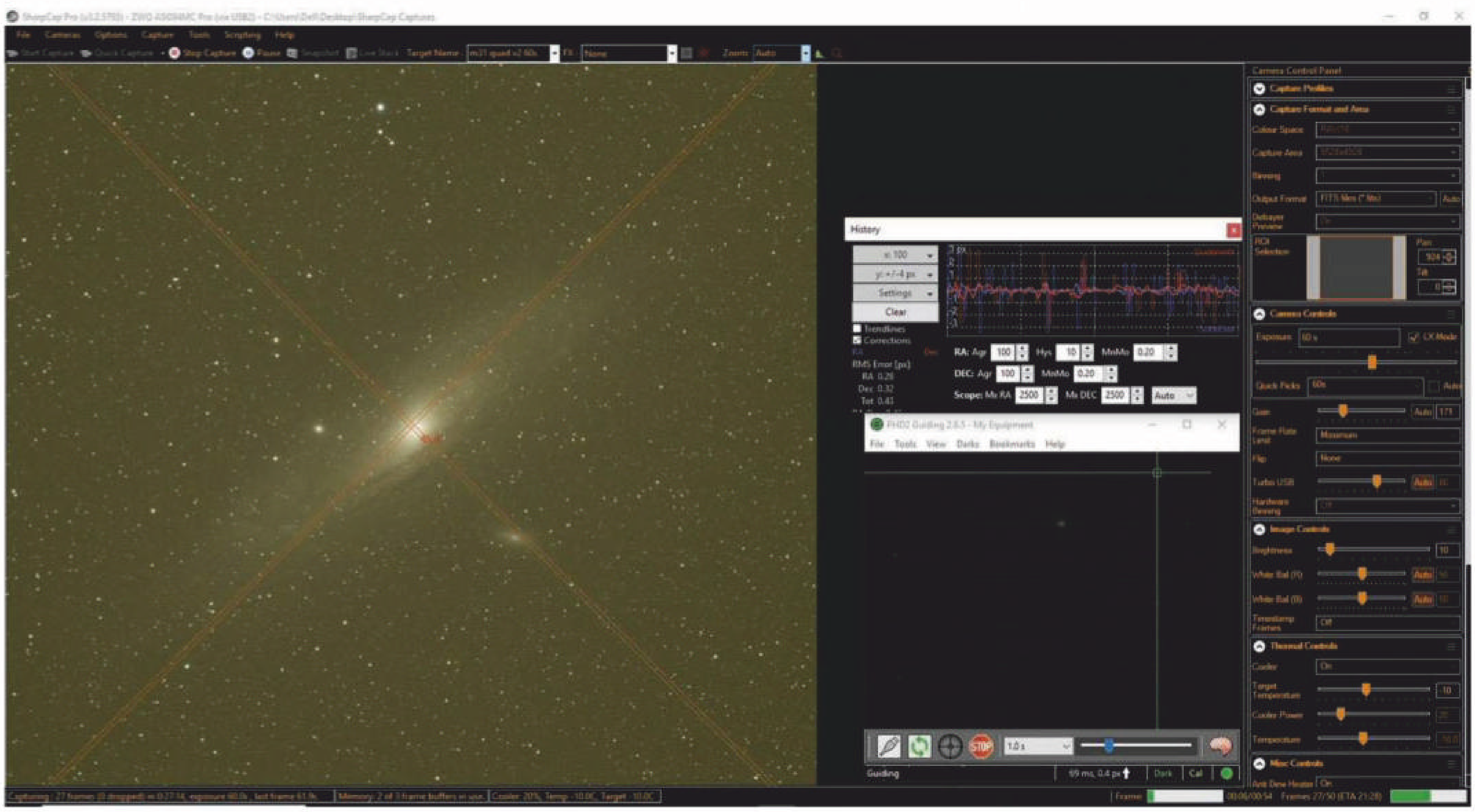
Camera connection and capture

Many CMOS cameras come with a high-speed USB3 blue connector. This is a dual port and has the normal USB2 connector inside it. When it comes to imaging deep-sky objects, the most stable setup is the USB2 method, as it is not so reliant on cable length or USB power output from the PC connections

Settings

Getting the settings right on CMOS cameras can be confusing, and one important step in particular is choosing the best gain setting. Gain steps are set by the manufacturer and are different in each model. Take, for example, the Sony IMX290 CMOS sensor. On cameras with this chip, if the gain is set too high it will introduce lots of noise, so it's better to keep it around 200 to 300. With other cameras it's a case of experimenting to find the best level, but in general CMOS cameras don't need the gain to be set as high as your average CCD camera; it's best kept to a range of between 150 and 450.

The next couple of settings to get right are image format and the camera's bit mode. The format needs to be set to FITS for the best capture and subtraction of calibration frames, while bit mode should be set to RAW and the highest bit number available, whether that's 12-bit, 14-bit, 16-bit or more. If the



The SharpCap capture screen with PHD2 guiding – this is the setup we used to control the camera settings while imaging M31

GARY PALMER X 4. WWW.THESECRETSTUDIO.NET

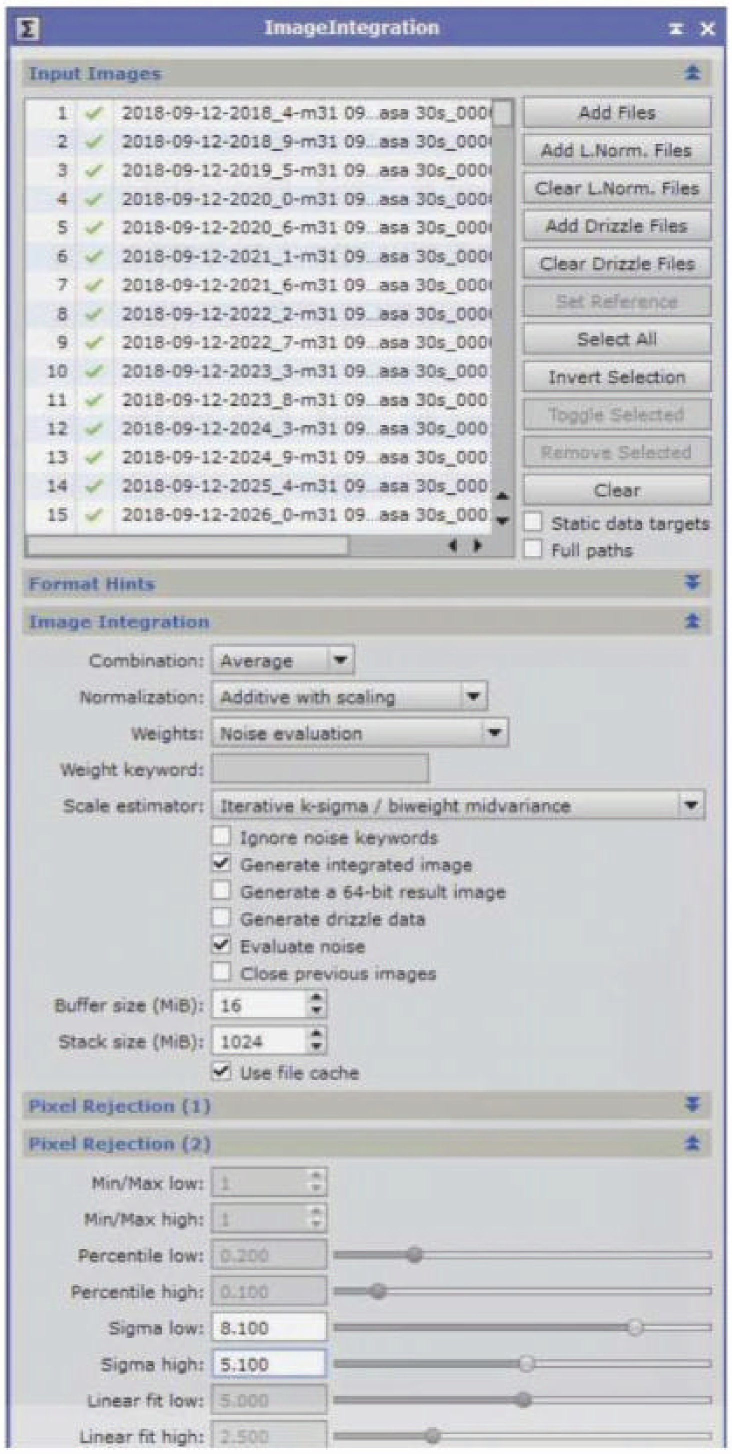
SECRETS TO SUCCESSFUL CALIBRATION

There are some surprisingly analogue aspects to getting effective dark frames

Poor subtraction in dark frames can cause all sorts of problems. Issues like 'digital rain' in the background of images and poor subtraction of the starburst or ampglow can be a challenge to correct. To fix this, dark frames need to be captured for the same length time as the main images: if you're capturing 60-second exposures, you need 60-second darks. If the camera is cooled, then capturing the dark frames around the same temperature as the light frames will help reduce background noise in the stacked image.

It's common practice to capture dark frames at a different time to an imaging session. But if the darks are captured on different length cables to the light frames this can cause all sorts of problems in getting a good subtraction. In my setup the cables are 7m long, running to a warm room next to the observatory where the computers are based. They're USB2, with the imaging camera on its own lead directly to the computer, not through a hub that has the guide camera connected. If the darks are captured on a short cable connected to a local computer the resulting subtraction can contain lots of coloured hot pixels and a digital rain across the image.

The Celestron RASA with a temporary cover to capture flat frames. Right: A dew heater controller mounted underneath the telescope



► **In PixInsight, Image Integration is where you stack the registered images that are produced from the Preprocessing Script. Satellite trails and other imperfections can be removed here**

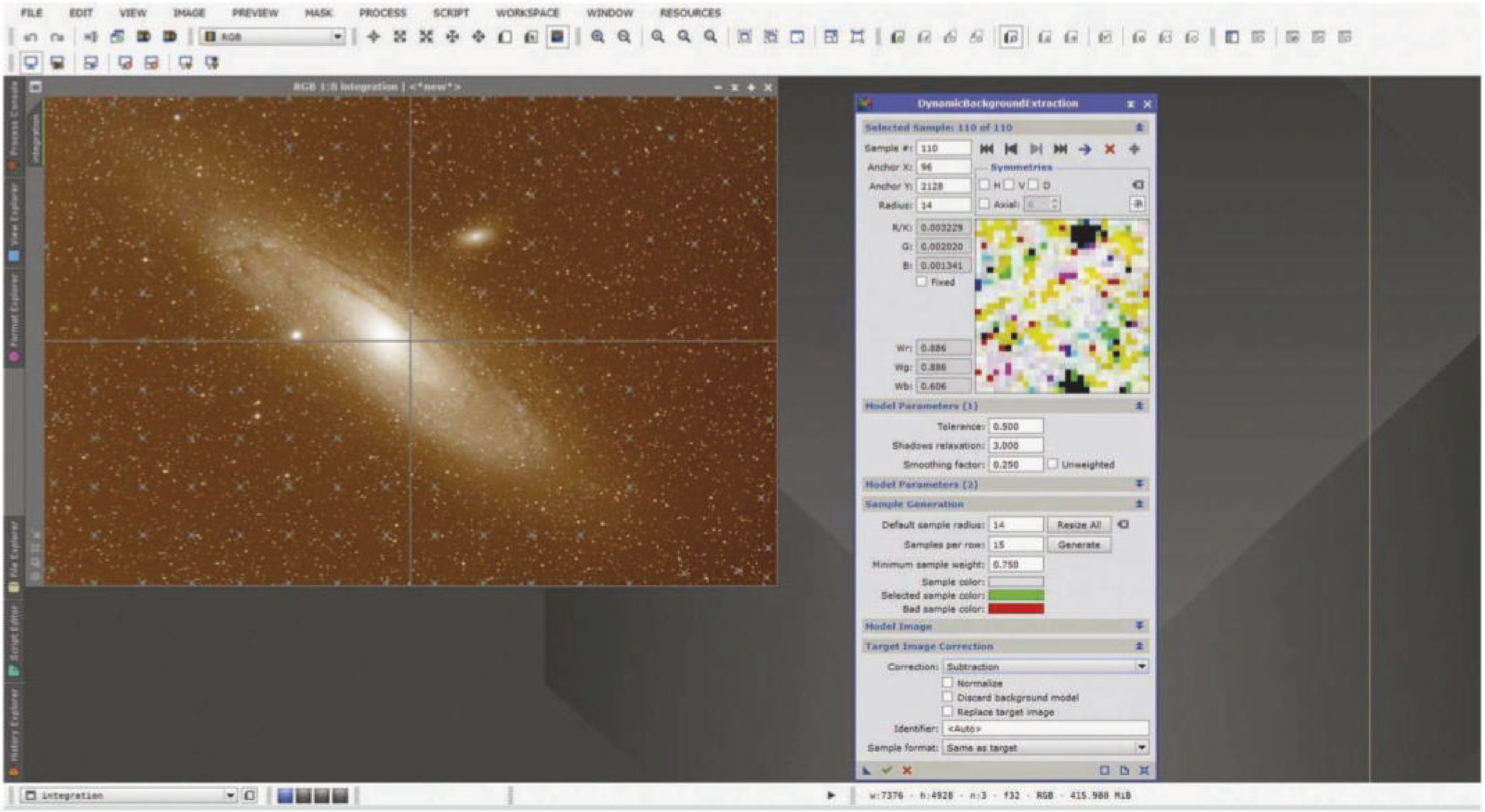
camera is set to a low bit mode, say 8-bit, it's likely to produce poor images with lots of background noise when used for deep-sky imaging.

If the camera has cooling, then we need to switch it on and let the system settle for a bit before capturing. CMOS cameras really don't need to be cooled to –30°C; generally around –15°C will give the best results. Setting the exposure, each camera will react differently depending on the focal length of the telescope it's being used with. For a popular sensor like the Sony IMX183 on an 80mm f/6 telescope, start with 60 seconds for the exposure and a gain setting of around 300, capturing around 100 images at that setting. Some of the latest cameras on the market have a new HGC (Hybrid Gain Control) noise reduction that switches on automatically as the gain is increased.

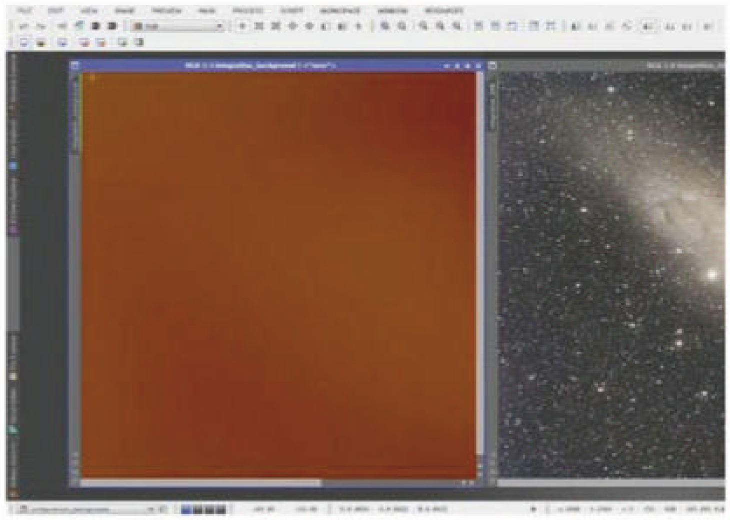
We used the capture software SharpCap (www.sharpcap.co.uk) to control the settings for the image of the Andromeda Galaxy; it can be used with many different CMOS cameras. Once captured, naming the files with the equipment and the exposure time used helps to match calibration data when it comes to processing.

Calibration frames

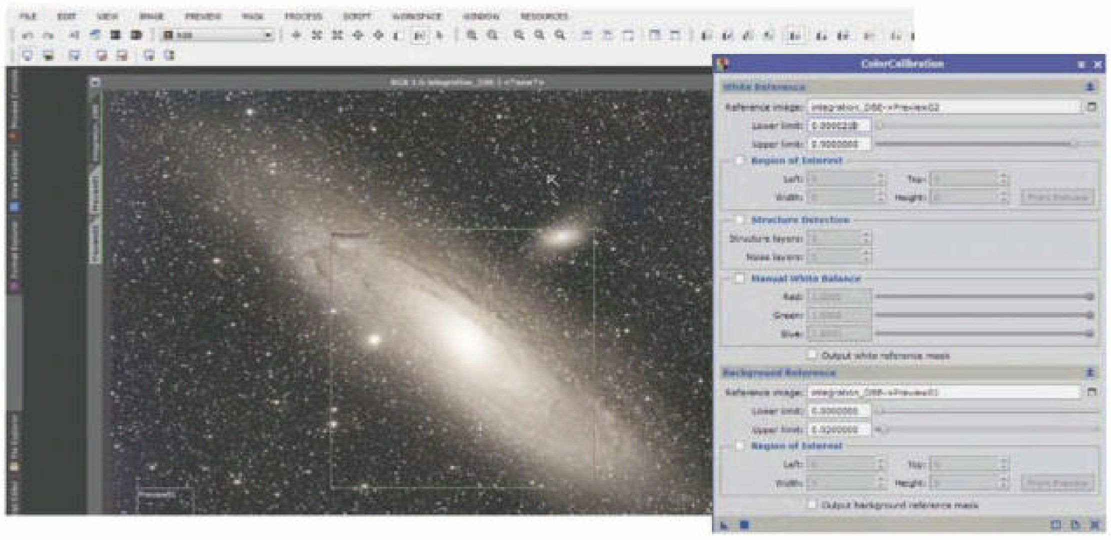
The capture of good calibration frames is just as important with CMOS deep-sky images as they cut down on the amount of correction needed in final processing. Use darks, flats and bias frames – despite there being some debate on whether the latter upsets the stacking of images, they do work for me. I capture bias frames at around two seconds and that prevents any problems upsetting the subtraction in processing. From experience, flat ►



▲ PixInsight's DynamicBackgroundExtraction (DBE) is the point at which you remove light pollution and other unwanted background colour



▲ Once DBE has been applied you can see the unwanted colour it has removed, nicely cleaning up the image



▲ ColorCalibration is where you get PixInsight to set the correct colours for the image

▸ frames have given mixed results: subtraction was not always good with some CMOS cameras that had vignetting. I made a change to capturing flats, getting them in daytime with a thicker cover over the telescope or using a flats panel on the front of the telescope. With full-frame CMOS sensors on reflector telescopes this seems to have removed the vignetting. Capturing around 30 frames of each of the darks, flats and biases works well, and after processing they are saved as masters for reuse. This cuts down on processing time as images from large format cameras can take a long time to process in any software.

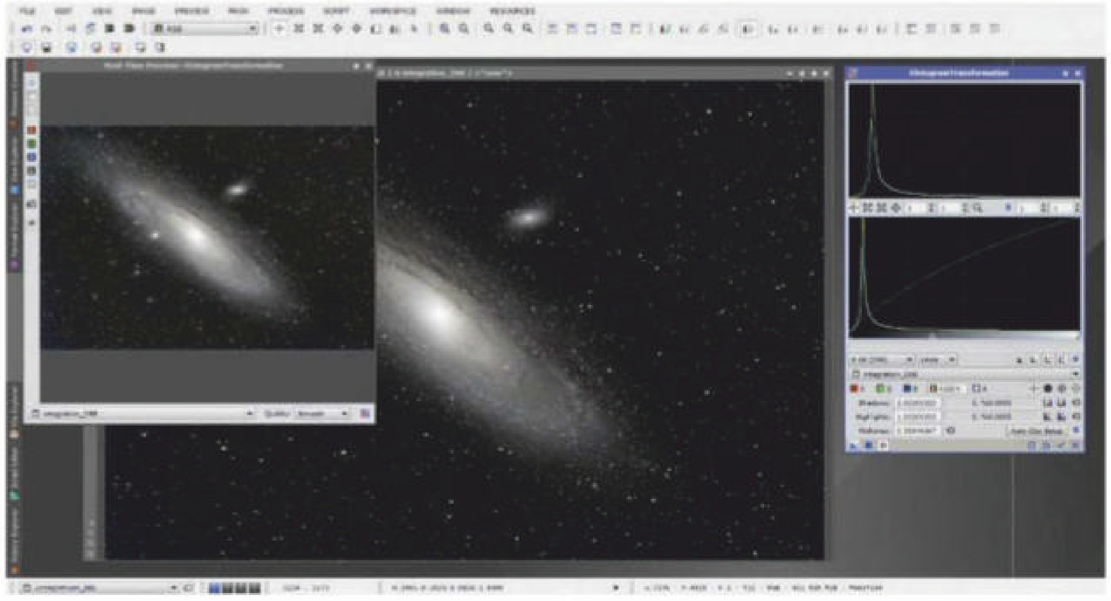
Image calibration

PixInsight is my go-to software for calibration and processing of CMOS images. Using its 'batch preprocessing' you can load in images and calibration frames, and it is here that you need to set up the camera to read the Bayer matrix correctly. FITS files can be read from the top down or the bottom up, and how they are saved depends on the camera and capture software. In the 'FITS' header file of each image you'll find useful information like Bayer settings, Exposure and Gain settings and the temperature the camera was set at for the capture.

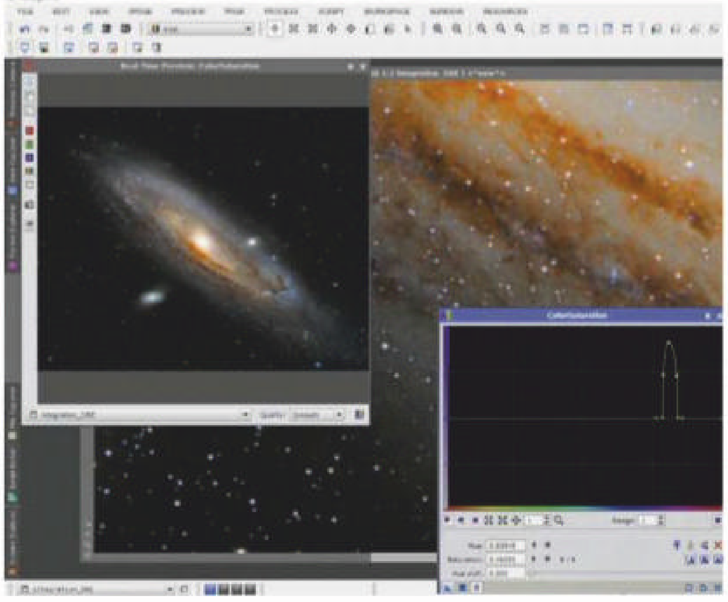
Using pics taken with an Altair Hypercam 183C CMOS camera as an example, in some software the colour would be set to RGGB, but it needs to be set to GBRG and the box marked 'Up-Bottom FITS' needs to be unchecked, which PixInsight allows you to do. This will then read the colour correctly and sets PixInsight apart from some other software.

"Capture about 30 frames each for the darks, flats and biases and after processing save them as masters for reuse"

GARY PALMER X 5



▲ **The next step is HistogramTransformation, which is when you can really bring out the hidden detail in the image. The key here is not to overstretch the image**



▲ **Colour saturation is applied to bring out the colour in each individual part of the image**

Getting the colour correct at the start of our processing is a really important part of the processing structure.

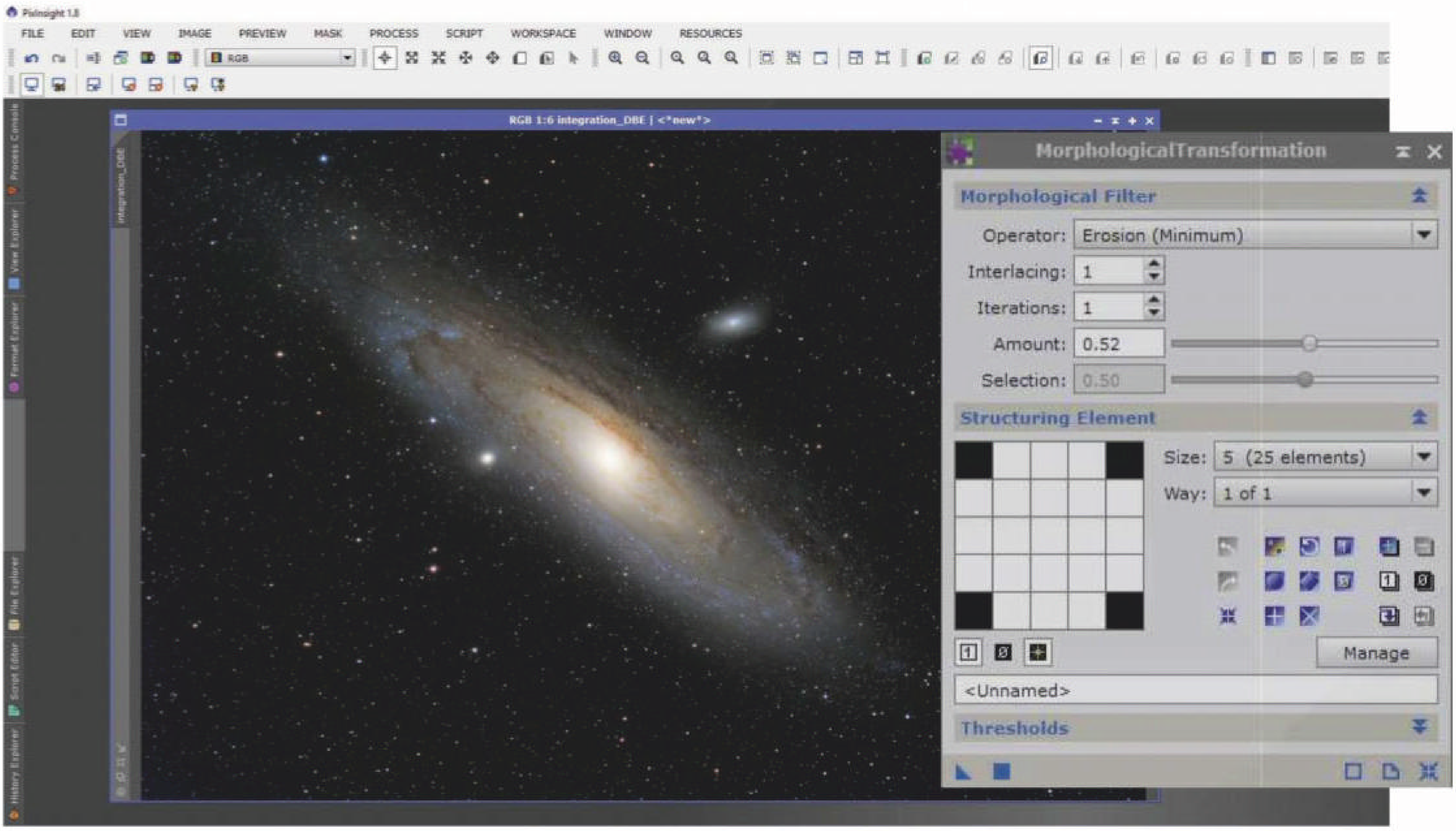
For my M31 image it took around an hour to calibrate the images. Some programs like DeepSkyStacker are faster but can't read the Bayer matrix in the same way, so the colour is stripped in calibration and this can lead to quite poor results.

Processing

If you need to get used to PixInsight for processing, the best thing in each part of the workflow is to play a little with the settings to see what you prefer for your own data set. At points through the processing, save the image you're working on as a project in the 'Save' options. This allows you to revert back to it if you make a mistake or need to stop and continue processing at a later stage. Remember that, when the image first loads on screen it will be very dull as it hasn't had its histogram stretched. To brighten the image initially without modifying it, use the 'ScreenTransfer' function.

The processing workflow is set to address parts of the image before stretching and after. Parts of the PixInsight workflow to consider before stretching are: 'DynamicBackgroundExtraction', 'BackgroundNeutralization' and 'ColorCalibration', before using the 'MultiscaleLinearTransform' to remove background noise in the image. 'HistogramTransformation' is then applied to bring out the detail in the image permanently. After stretching, the workflow continues with 'CurvesTransformation' to add more colour, then 'MorphologicalTransformation' to tighten the stars. Finally 'ColorSat' adds selective colour to stars and local parts of the image. Once finished you'll see a visible improvement in the picture. Ⓢ

▼ **Morphological Transformation is applied to reshape and shrink the stars. It will flatten the smaller stars helping to bring out detail in the main object**



SKILLS

Brush up on your astronomy prowess with our team of experts

The Guide

With
Steve Richards

Why is stacking vital for astrophotography?

The alternative to long, single exposures that will best capture deep-sky objects

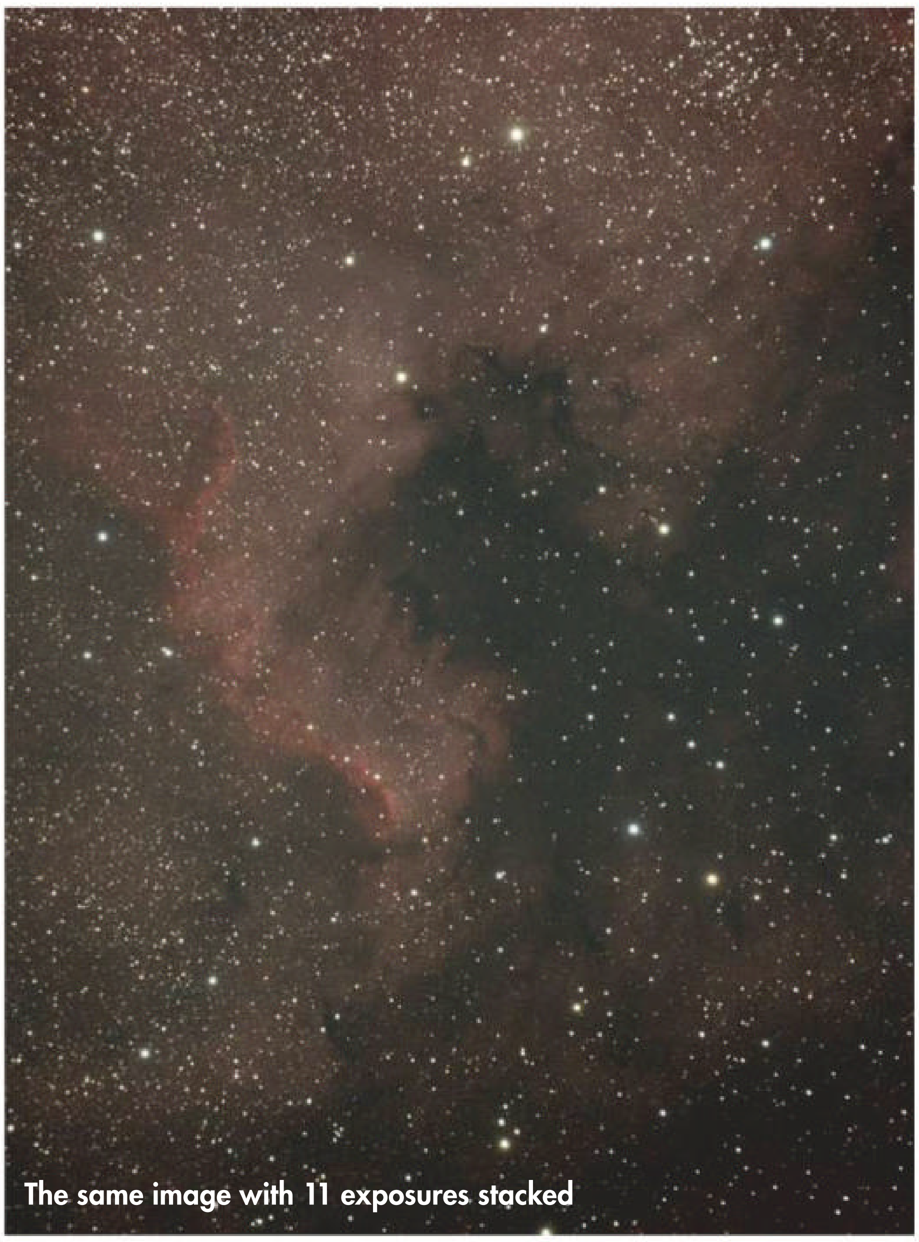
Having seen the amazing deep-sky images amateur astro imagers produce these days, you're no doubt pondering having a go yourself. In which case it won't be long before you come across the term 'stacking'. But what is that mean and why is it so important to astrophotography?

Stacking, also known as integration, is all about increasing the signal-to-noise ratio (SNR) of your images; in other words, increasing the signal that you do want and reducing the noise you don't. Every image you capture contains both signal and unwanted noise. Over time the noise level grows at a slower rate than that of the signal so very long exposures produce higher signal-to-noise ratios resulting in smoother, cleaner, more detailed images.

However, there are limits to the exposure lengths you can achieve. These limits are set mainly by: the accuracy of your mount's tracking; the amount of light pollution and atmospheric conditions at your location; the sensitivity of your camera; the focal ratio of your telescope; how bright the object is you're imaging; and the risk of exposing your image until the pixels over-saturate. Meanwhile, images captured at too short an exposure will fail to pick up the very dimmest details in your target.

Instead of long exposures, then, astro imagers shoot as many similar images of their target as they can and then combine them into a single image using stacking.

A single-exposure, colour image



The same image with 11 exposures stacked

ALL PICTURES: STEVE RICHARDS

You've been framed

Your starter's guide to calibration frames – what each one does and how to create them

Type	What it is used for	How you produce one
Bias frame	Removing the readout signal from you camera sensor – even when a pixel has not received any sort of signal there is still variation in how the camera reads data off the sensor	Cap the telescope and take the shortest exposure possible
Dark frame	Correcting the variable dark current generated in each pixel as the sensor warms up during long exposures that can produce what are known as 'hot pixels'	Cap the telescope and take exposures that match the length and temperature of your image captures (which are known as light frames)
Flat frame	Correcting the variable light sensitivity of pixels across the sensor; correcting vignetting and removing the shadows cast by dust particles	Capture an image while the telescope is pointing at a uniformly illuminated light source with the focus set at the same position used for the light frames

There is no hard and fast rule for the number of images required for the process but typically a batch of around 20 images is ideal, though any number over five will yield noticeable improvements.

So, how does stacking actually work? The key to it is that unwanted noise in a typical image tends to be random across different exposures whereas the desired signal is consistent. When a set of images is stacked, the individual image values are averaged, which means that the random noise overall diminishes but the signal remains constant. This means that the ratio of the signal to the noise increases, resulting in a much cleaner, more detailed image with a smoother background.

Dynamic ranger

As well as striving to increase the SNR of their images, astro imagers also aim for a wide dynamic range. Dynamic range is the spread of brightness levels from the dimmest recorded light value that can be captured to just before pixels become saturated.

Objects with a wide dynamic range include the Andromeda Galaxy and the Orion Nebula, with their intensely bright cores and much fainter outer regions. A single image of these could easily reach saturation on the brightest areas before the dimmer details have registered at all. But when you stack several unsaturated images together, the dimmer values accumulate into higher values, bringing fainter objects over the bottom limit of the dynamic range (in other words, you can start to see them), while at the same time the brighter values increase as well. Stacked images, therefore, display a wider dynamic range.

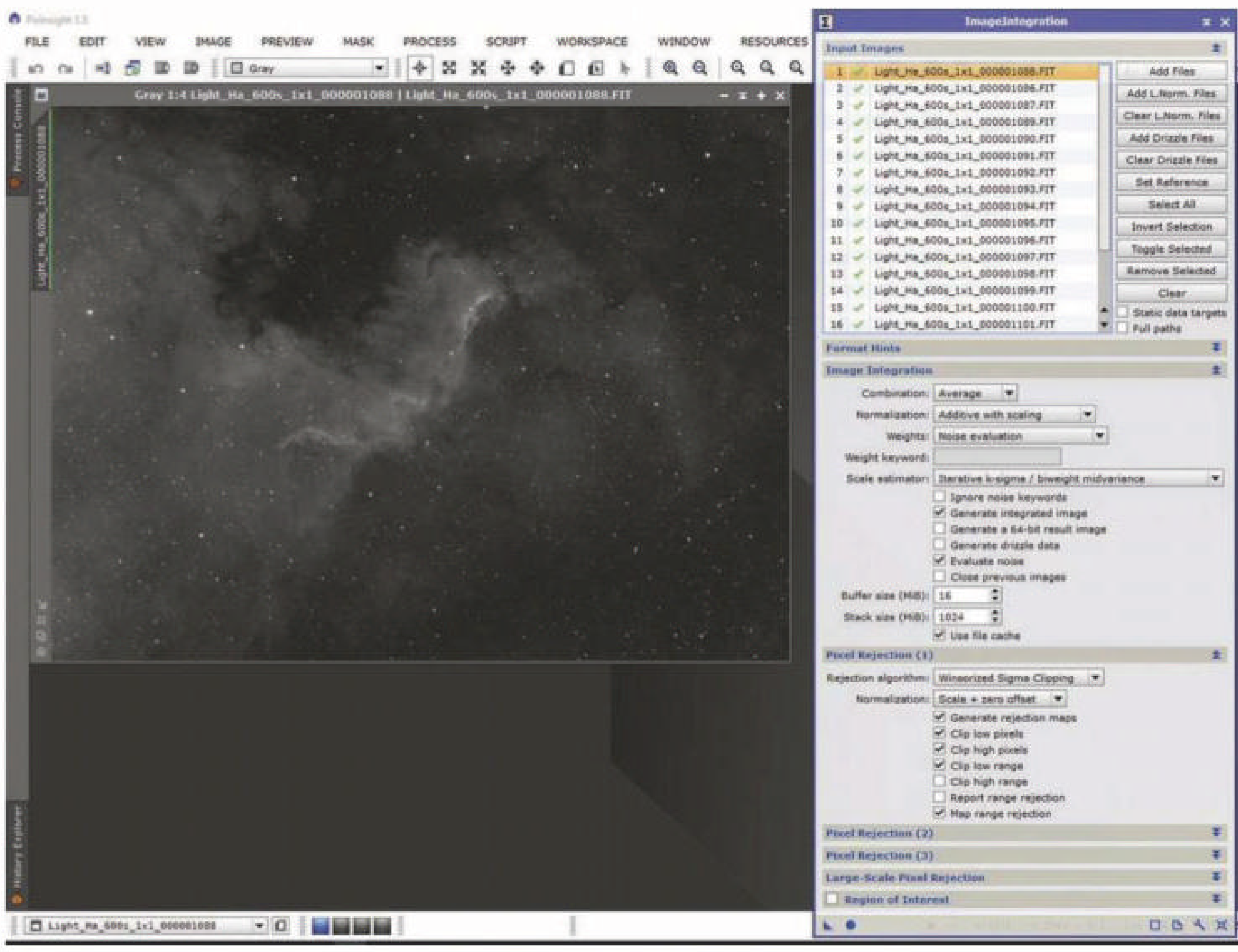
To take advantage of this seemingly win-win process, a few additional steps need to be carried out. Noise isn't limited to the quality of the signal received by the sensor. There are unwanted signals generated by the camera's sensor itself; thermal noise as the sensor warms up during long exposures; variations in pixel-to-pixel sensitivity; shadows caused by dust particles; and vignetting of the light cone. This additional degradation of the image is tackled by a process called calibration, which involves capturing extra one-off frames that are included in the stacking process to 'subtract' noise (see the box-out above for more details).

A useful piece of jargon to know at this point is that all the individual shots of your target image are called light frames when it comes to the calibration process.

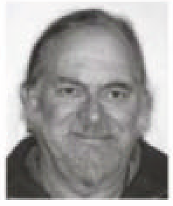
Once the images have been calibrated, they need to be aligned with one another before the stacking. The calibration, alignment and final stacking processes can be easily carried out using specialist astronomy-based image processing software. DeepSkyStacker is an excellent free program but other commercial image processors like Astroart, Astro Pixel Processor, MaxIm DL, Nebulosity and PixInsight are worth considering.

As ever, your best bet is to start small, experimenting with a few frames on easy objects, and work up from there. Because mastering stacking is a key skill when it comes to truly awesome deep-sky images.

STEVE RICHARDS is the author of *Making Every Photon Count: a Beginner's Guide to Deep-Sky Astrophotography*



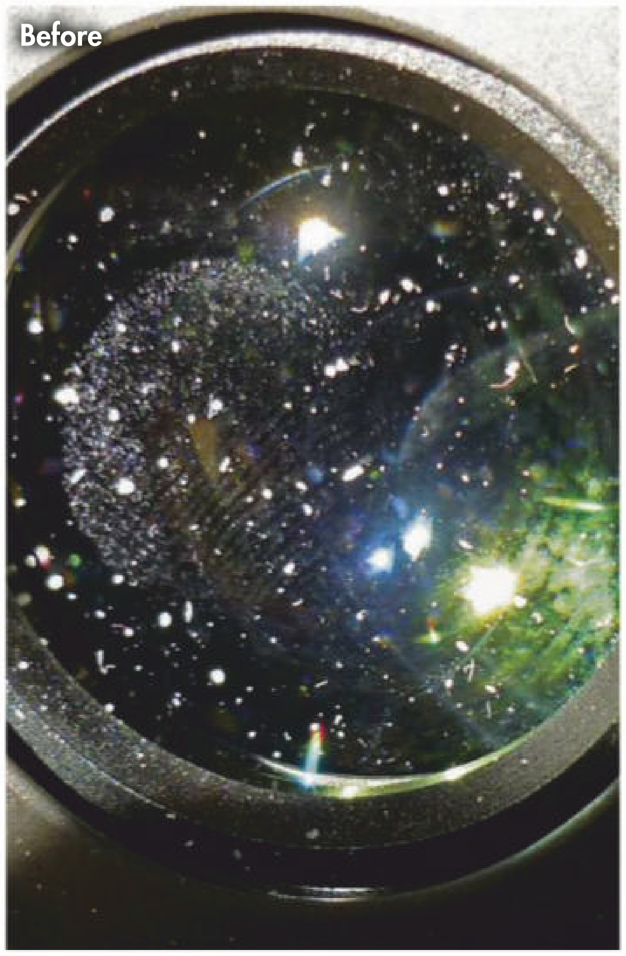
▲ PixInsight is one of a number of image processing programs available that automatically calibrate, align and ultimately stack your images to produce your final masterpiece

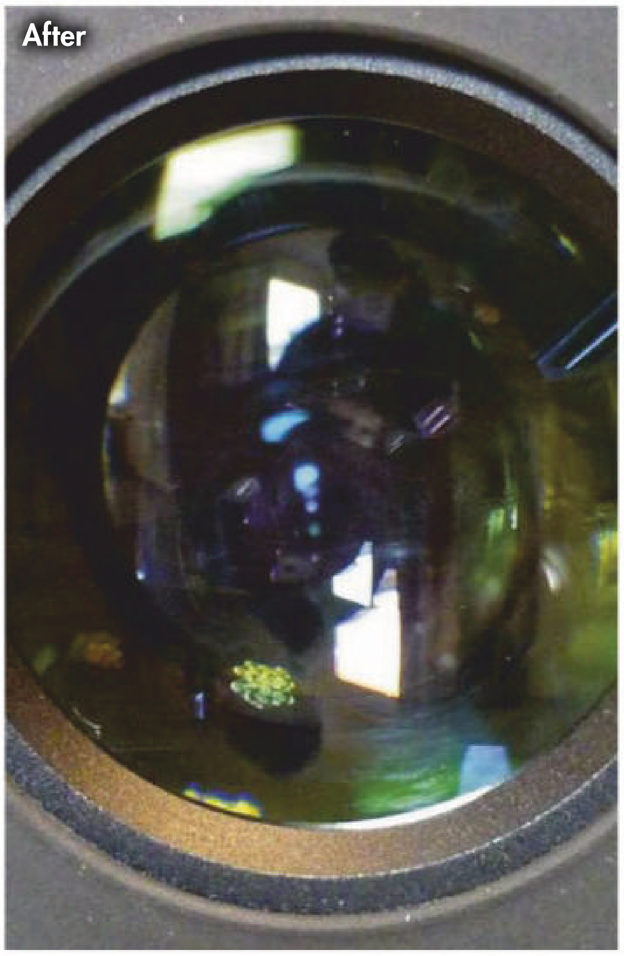


With
Steve Tonkin

How to...
Clean your binoculars

There's more to keeping delicate optical devices clean than spit and polish





▲ **Grime and punishment: dirty lenses lead to a drop in performance, so keep them clean**

There is an old adage that the best way to clean any piece of optical equipment is to prevent it getting dirty in the first place. Obviously this isn't practical if you plan on doing something as reckless as actually using your binoculars, but you can certainly reduce the frequency of cleaning if you're careful.

Almost all binoculars come with cases and a set of lens caps; keep them clean, inside and out, and make use of them whenever your binoculars aren't in action. Please don't assume that lens caps alone are sufficient; they are not. While it's essential to keep the lenses as clean as possible, you also need to reduce the amount of dust that penetrates the various mechanical parts of your binoculars, especially the focusers and hinges, where it can increase the rate of wear.

Also, any grime that falls off the body of the binoculars could fall into their case or onto the inner surface of a lens cap, from where it can be transferred to an optical surface. Your fingers might also pick up dirt from the body of the binoculars that could end up on the lenses.

In practice it is the optical surfaces, particularly the eyepieces, that are the most susceptible to damage. Never be tempted to leave your binoculars uncapped, standing on a windowsill. The eyepieces will immediately begin to accumulate dust, which has the potential to damage the lens coatings when it's wiped off, particularly if done inexpertly.

You will probably find that your eyepiece lenses get dirty much more quickly than the objective lenses do. This is largely because binoculars are eyepiece-up when you hang them from your neck, making the eyecups perfectly positioned receptacles for dust, pollen, cake crumbs, drips of coffee or any other contaminant that seems to be attracted with magnetic precision towards any exposed optical surface. Standard individual eyepiece caps are not very convenient to use during an observing session, but a rain guard, tethered to the neck strap, is ideal. If you make a habit of covering the eyepieces when you take the binoculars from your eyes and let it hang, it will soon become second nature, and you'll find your eyepieces stay much cleaner.

TOOLS AND MATERIALS

▶ A bright light for examining the lens before and after cleaning.
▶ A cloth and cotton buds for cleaning the outside of the binoculars and the inside of the lens caps.
▶ A puffer and lens brush for removing loose dust and debris.
▶ Lens tissue (kept clean in a ziplock bag) for doing the bulk of the optical cleaning; if you don't have lens tissue, a viable alternative is a very clean microfibre cloth.
▶ Lens-cleaning fluid or isopropyl alcohol for marks that won't puff or brush off.
▶ A lens pen for cleaning off accidental fingerprints or water marks when you're observing in the field.

Grime crimes

There's not a lot you can do about the objective lenses. They accumulate little grime when they're hanging downwards from the neck strap, but when you're using them, they're inevitably directed upwards, in a detritus-collecting orientation.

No matter how careful you are, your lenses will eventually need cleaning. Small amounts of ordinary dust are best left; this ▸

ALL PICTURES: STEVE TONKIN

▲ Keep an eyepiece rain guard tethered to the neck strap when observing out in the field

► doesn't noticeably affect the image and, as long as it is not wiped, it won't harm the lens. However, there are some offenders that should be removed as soon as possible: pollen, fingerprints, eyelash grease, cosmetics and dew. Pollen can be particularly harsh: some pollens are sticky, extremely sharp-edged and capable of etching lens coatings. Fingerprints, eyelash grease and some cosmetics can start to etch the lens surface if they are left for a few days.

Dew is inevitable in Britain. It's a good idea to wipe it off the body of the binoculars with a clean cloth (you'll take some dust off with it), but never wipe it off a lens; let it evaporate. You can speed this up with a hairdryer (for field use, a 12V camping hairdryer is usually a fraction of the cost of a dedicated astronomical 'dew-gun' that does the same job). Initially you should point the hairdryer away from the lenses so that any dust that's settled inside the dryer isn't blasted at them. Otherwise just leave the binoculars, uncapped and horizontal, somewhere warm and dry for a few hours. Moisture is ruinous to binoculars, so always keep a sachet of silica gel in their case so that any residual moisture is absorbed.

When you clean your lenses, the watchword is 'care'. Never be tempted to use a handkerchief or the hem of your tee-shirt, but carefully follow our cleaning advice, and your binoculars will continue to give you their best. S

Binocular astronomy specialist STEVE TONKIN has written multiple books in the *Patrick Moore Practical Astronomy* series

ALL PICTURES: STEVE TONKIN

STEP BY STEP

STEP 1
The dirtiest part of your binoculars will almost certainly be the body, so use a clean, barely damp cloth to wipe down as much of the body as you can, and use cotton buds for any difficult-to-reach areas. Don't neglect the insides of the lens caps!

STEP 2
A bright light will reveal any contaminants that have accumulated on the lens. With the binoculars horizontal so that dust cannot fall onto the lens, use a puffer – with the lens brush if necessary – to remove loose dust and flakes of debris from the lens.

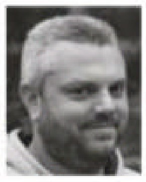
STEP 3
Scrunch up a sheet of lens tissue, then roll it loosely and tear the roll in half to make two paper 'brushes'. Spray lens-cleaning fluid on one of the torn ends and gently clean the lens, starting in the middle and carefully working your way outwards.

STEP 4
When you've cleaned the entire surface, use the second lens tissue 'brush' to gently polish the lens, again starting from the middle and working outwards. This should remove any residual cleaning fluid. Blow off any dust that collects on the lens during this process.

STEP 5
When you think the lens is clean, breathe on it to reveal any remaining marks or smears, and remove the condensation with another lens tissue. Then re-examine the lens under your bright light and repeat the cleaning process if it's not yet properly clean.

STEP 6
A lens pen is ideal for 'emergency' cleaning if you accidentally get a fingerprint or other small mark on the lens while observing. Use the retractable brush to remove any dust from the lens, then work from the centre outwards with the carbon pad.

Image PROCESSING



With
Ian Evenden

Improve your deep-sky images with luminosity layers

Creating a brightness-specific adjustment layer in image editing software will enhance details

▲ **The galaxy M106 taken using an ED80 apo refractor and GPCAM 290C camera, showing the difference a luminance mask can make**

Luminosity is the name given to the brightness information contained in a photograph. It is also the term that provides the L in a number of acronyms commonly encountered by astrophotographers, such as HSL or RGBL.

Thanks to the funny way the human eye works, the luminosity information in an image file contributes more toward the perceived sharpness of the photo than the colour information does. Viewed on its own, the luminosity data looks like a black and white version of the image, and owners of mono CCD cameras will be familiar with it because this is what their cameras produce without a coloured filter in place. With such a camera, you can acquire your luminosity data at full resolution, but then drop the image size when shooting with colour filters to save time during the acquisition process – a process known as binning. This makes the details look so much sharper.

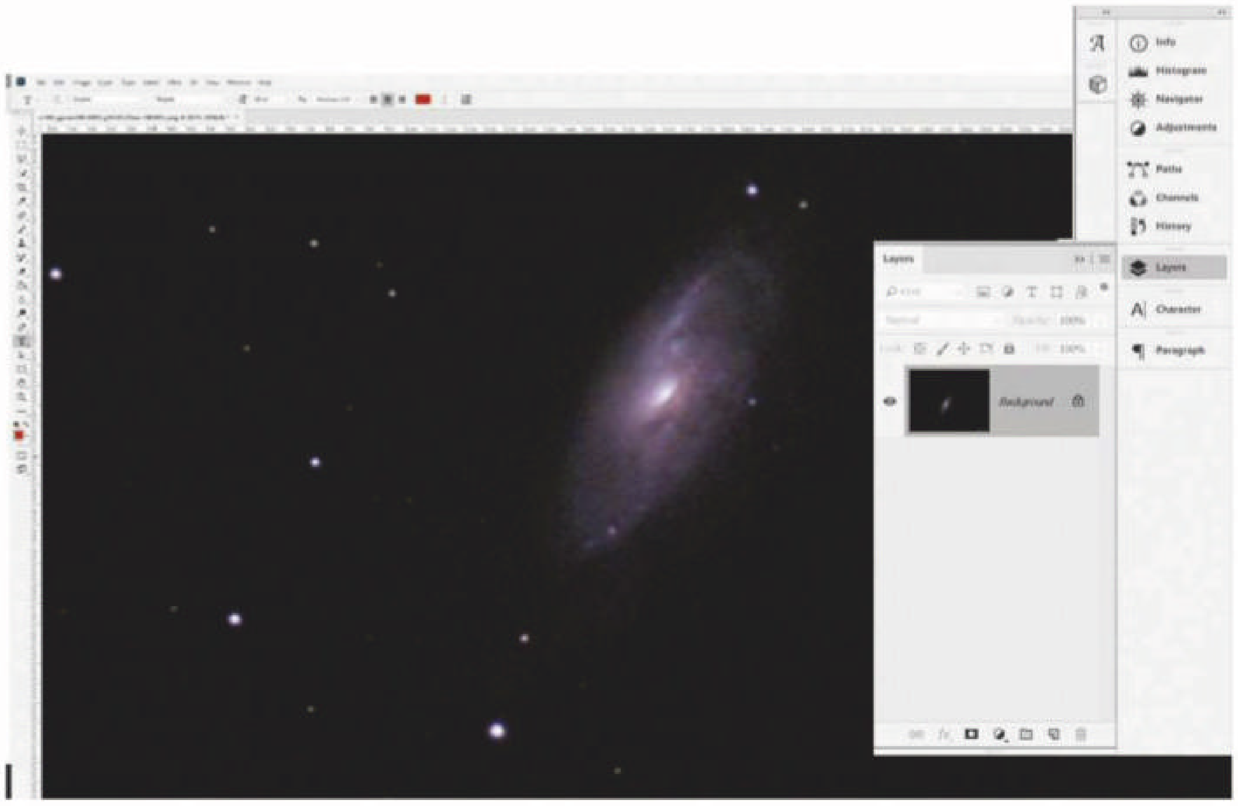
For those using RGB astro cameras or DSLRs, separating out the luminosity data can be done, but it is a purely synthetic process, and doesn't have the same benefits. However, if you're editing your photos in an application such as Photoshop, Photoshop Elements or Affinity Photo, you can create an Adjustment Layer that edits only the brightness values of an image, which, when blended with the colour layers, really enhances the details.

We're going to use a Curves Adjustment Layer, although you can also choose Levels or Exposure. To create the luminance layer, open your image in one of the apps mentioned above (we're using Photoshop CC), and open the Layers palette (Window > Layers if it's not already visible). At the very bottom of the right-hand palette you'll see a half black, half white circular button; click on this to open a drop-down menu revealing all the available Adjustment Layers. We're going to choose Curves.

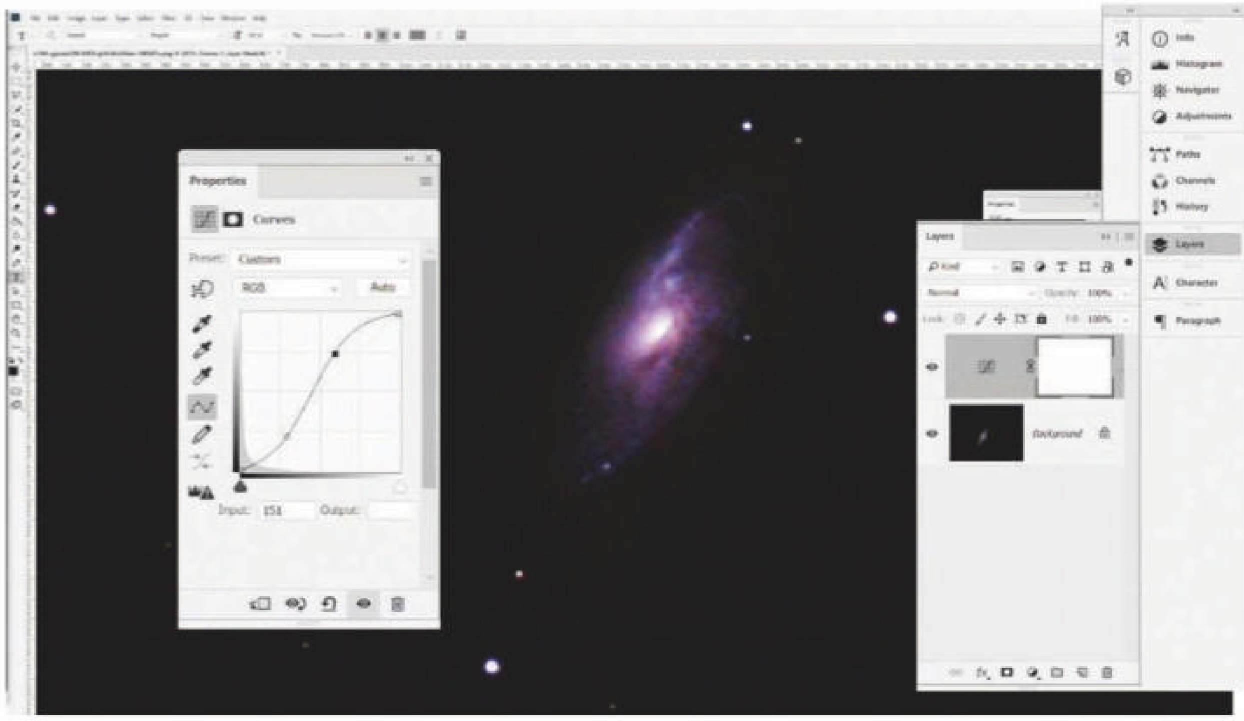
Set the tone

The new layer appears on the top of your Layers stack. As we've only got one other layer, it's fairly straightforward, but if you've got several layers in play it can be worth arranging them so anything you don't want to be affected by the Curves adjustment is above it.

ALL PICTURES: IAN EVENDEN



▲ An adjustment layer lets you modify your image and discard any changes if you go wrong



▲ Fine-tune dark and light tones by dragging control points on the Curves histogram

Our image is of the spiral galaxy M106 in the constellation of Canes Venatici, close to The Plough asterism and M51, the Whirlpool Galaxy. It was taken with an GPCAM 290C camera and an 80mm apo refractor. The galaxy is notable for being large and bright, so it makes a good target to go for as an alternatve to Andromeda.

The Curves Adjustment Layer comes with a Properties window that contains the Curves histogram itself. By moving points on the graph, you control how tones in the image are displayed. So, by dragging a point at the bottom left, you darken or lighten dark tones, and at the top right you darken or lighten light tones. An S-shaped line often comes out well, darkening space and brightening stars and DSOs, although what looks best depends on your photo and personal taste.

To make it a true Luminosity adjustment, though, we need to take one more step: change the Blend Mode of the Adjustment Layer to Luminosity. You'll find the drop-down at the top of the Layers palette, and it probably says Normal. Luminosity is the very last entry on the menu. Your image may change noticeably when the Blend Mode is altered. This is because Photoshop is now ignoring the colour information and applying the Curves adjustment purely to the luminosity information in the image.

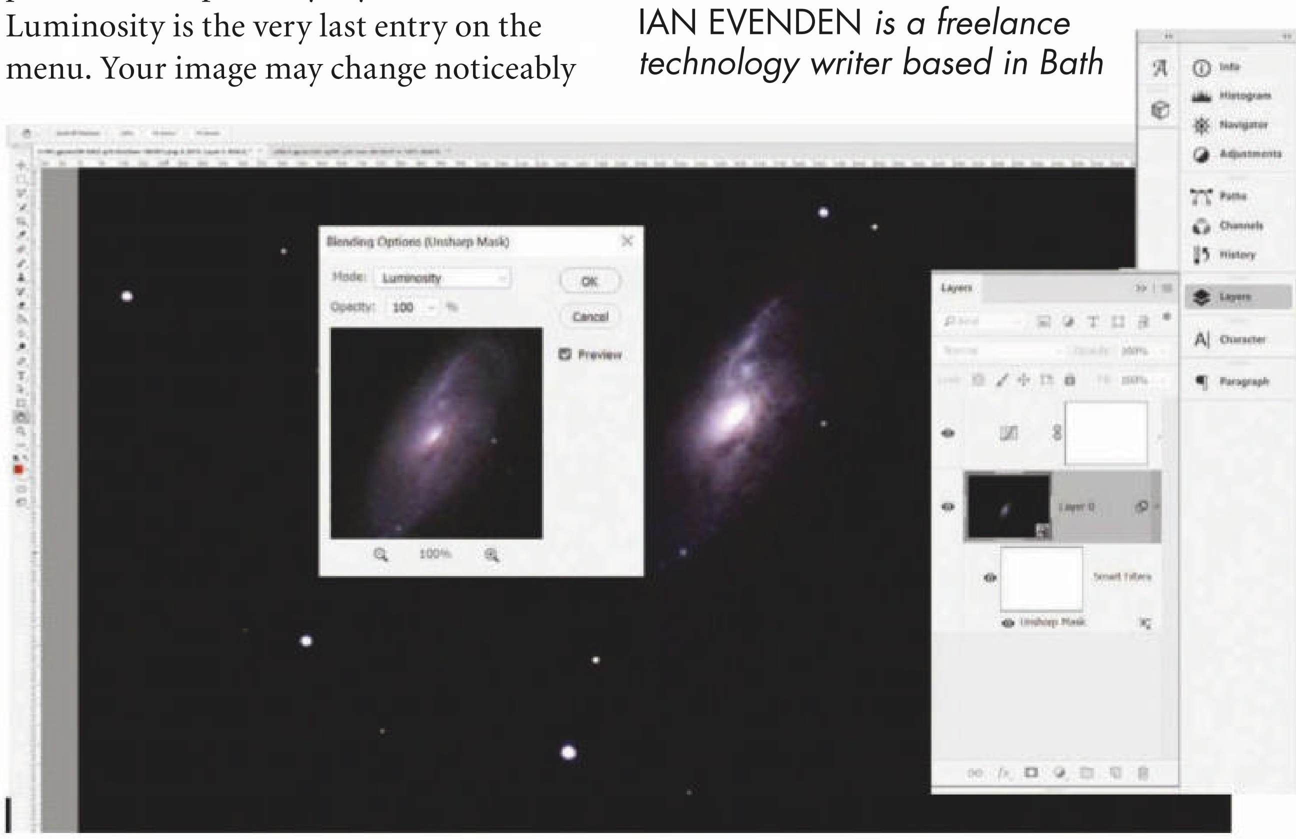
Adjustment layers are clever, but in Photoshop CC you can also apply filters as a layer and use the same technique to restrict them to just the luminosity information. Right-click your Background layer, and you'll find the option to Convert to Smart Object (alternatively, with the layer selected, go to the Filter menu and choose Convert for Smart Filters). Doing this causes all filters to be applied to the new Smart Object as Smart Filters, which act like layers and can be edited after they're applied, as well as blended.

Look sharp

We're going to apply the Unsharp Mask filter as a Smart Filter. Click on Filter in the top menu bar, select Sharpen from the drop-down menu, then Unsharp Mask from the next menu to appear. Click OK in the window that appears and the Smart Sharpen filter will appear in the Layers palette, with an icon that looks like two little lines with triangles beneath them. Click on this icon to open the Blending Options window, from where you can select Luminosity from the drop-down menu.

When it comes to saving your layered file to work on later, you'll need to use Photoshop's native PSD format (or .afphoto for Affinity), as all other file formats will flatten the layers into one. Use File > Export to create a PNG version of your image if you want to share it online. S

IAN EVENDEN *is a freelance technology writer based in Bath*



▲ Change the blend mode to Luminosity so your adjustments don't affect the colour information

Scope DOCTOR

With **Steve Richards**

Our equipment specialist cures your optical ailments and technical maladies

A 6-inch scope plus a light mount like this Vixen Porta II make for an easy-to-move setup

I struggle when travelling with my 200P Dobsonian. Do you have any advice for transportation, or is it time to downsize?

ALAN DOWNE

Dobsonian reflectors represent some of the very best value instruments as you get a lot of aperture for your money and a no-frills but very stable mount. However, an 8-inch (200mm) reflector is a relatively large and cumbersome instrument – as you have discovered – so it may be worth simply downsizing a little so that you don't lose too much of that valuable aperture, but have a more manageable instrument to move around. A 6-inch (150mm) reflector would be an excellent compromise here, as this would still provide a very generous aperture but would be just that little bit smaller and easier to transport.

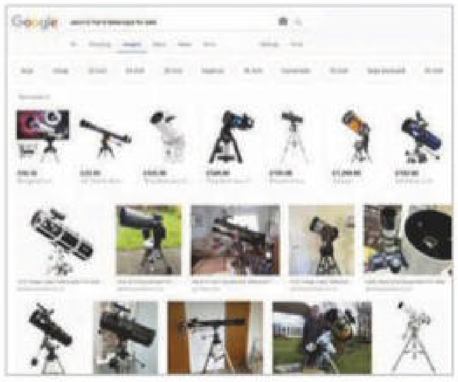
Unfortunately, the Skyliner 150P Dobsonian – made, like your current telescope, by Sky-Watcher – has the same 1,200mm focal length, so there would be no saving in overall length. However, Sky-Watcher does have a standalone version, the Explorer 150P, which is available in a shorter focal length of 750mm, and this could be satisfactorily mounted on a suitable altaz mount.

The 150P has the same focuser as the telescope that you are used to (a single-speed Crayford design), but in all other respects it is just a scaled-down version of your existing optical tube.

Mounts suitable for the 150P would include the Sky-Watcher AZ4 and the Vixen Porta II mount, both of which come equipped with lightweight but stable aluminium tripods.

To get the most for my money, I'm considering buying a second-hand scope. What should I consider before making a purchase?

BARRY FUDGE



▲ Used gear is often well cared for, but be wary of common faults

Buying second hand is a popular choice as astronomers generally respect their equipment to ensure they get the best out of it. But there are some safeguards that you can implement to further ensure that your purchase goes smoothly.

If the telescope has been used for astrophotography, ask the vendor to send you a recent photograph captured through the telescope and examine the star shapes closely, checking for any unwanted aberrations like astigmatism or flare.

Small marks on the outside of the optical tube are normal, but be very wary of dents as they're an indication the instrument has been dropped. Check the action of the focuser, ensuring that it is smooth with no flop in the focus tube. Examine the optics carefully under ordinary daylight, not with a torch.

General dust is quite normal, but look for any scratches or blemishes on the lens surface. If there are any signs of dust, moisture or fungal growth between any of the elements, walk away!

STEVE'S TOP TIP

What is an ED eyepiece?

Eyepieces contain several lens elements and these are designed using different types of glass to correct chromatic aberration – unwanted false colours, halos and colour fringing.

One type of glass that is particularly good at reducing chromatic aberration is known as ED glass. ED stands for 'Extra-low Dispersion' and lens elements made from this type of glass reduce the distance between the plane of focus of the various wavelengths of light to produce a more saturated image. Eyepieces with one or more ED lens elements produce more accurate colours, with less chromatic aberration than normal eyepieces.

STEVE RICHARDS is a keen astro imager and an astronomy equipment expert

Email your queries to scopedoctor@skyatnightmagazine.com

BBC Sky at Night MAGAZINE

Reviews

Bringing you the best in equipment and accessories each month, as reviewed by our team of astro experts

HOW WE RATE

Each product we review is rated for performance in five categories. Here's what the ratings mean:

- ★★★★★ Outstanding
- ★★★★★ Very good
- ★★★★★ Good
- ★★★★★ Average
- ★★★★★ Poor/Avoid

90

What puts the 'SD' in the Vixen SD103S? Some seriously impressive Super extra-low Dispersion optics, that's what

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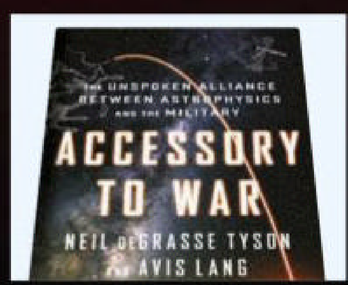
This month's reviews



Find out more about how we review equipment at **www.skyatnightmagazine.com/scoring-categories**

FIRST LIGHT

See an interactive 360° model of this camera at www.skyatnightmagazine.com/vixensd103s

Vixen SD103S apochromatic refractor

WORDS: PETE LAWRENCE

A portable scope that happily multitasks for both observing and imaging duties

VITAL STATS

- **Price** £1,649
- **Optics** SD103S Super ED glass (FPL-53)
- **Aperture** 4-inch (103mm)
- **Focal length** 795mm (f/7.7)
- **Focuser** Crayford-style, 2-inch standard with 1.25-inch adaptors
- **Extras** Tube rings, dovetail adaptor, 7x50 finder, flip mirror diagonal, carry handle
- **Weight** 4.7kg (10.4lbs)
- **Supplier** Tring Astro
- **Tel** 01442 822997
- **Website** www.tringastro.co.uk

Smaller aperture refractors, such as the Vixen SD103S apochromatic refractor we're reviewing here, are a popular choice for both visual and imaging tasks. The unobstructed aperture of these purely lens-based instruments delivers higher-contrast views that are superior to those achieved with reflectors or SCTs of similar size. With those types of telescope, it's the use of a secondary mirror that diffracts incoming light and ultimately reduces the view's contrast.

Where refractors do fail, though, is in terms of price per millimetre of aperture. A large aperture reflector or SCT will typically cost significantly less than a similarly sized refractor. In addition, while a large SCT is relatively easy to handle, a large refractor will typically be long, heavy and unwieldy.

The Vixen SD103S has a 103mm objective lens with a focal length of 795mm, making it an f/7.7 mid-speed instrument. This means that as well as being a fine instrument for visual work, the SD103S should make a superb imaging telescope. The SD103S's internal baffles have been redesigned from previous models to allow large sensors, such as those found in full-frame DSLRs, to be fully illuminated. In our tests we found that although this was the case, an amount of vignetting still occurs in the extreme frame corners, an issue easily fixed by flat-field calibration.

SKY SAYS... The high-spec optics simply ooze quality, producing images of stunning clarity and crispness

The focuser draw tube has a 60mm thread and is supplied pre-fitted with a 2-inch adaptor ring. The focuser is of the Crayford-style. Adjustments are basic with just a focuser stiffness tension knob. Tightened, this locks the focuser in position. We were impressed with the strength of the lock – even a heavy camera with a bit of manual assistance wouldn't budge.

Balancing act

The SD103S weighs in at 4.7kg and is extremely portable. A carry handle makes it very easy to transport and lift onto a mount. The supplied mounting plate is of the classic Vixen type rather than a rail and requires a smaller Vixen mounting clamp for a secure connection. Once mounted, the tube rings are easily loosened and tightened to allow the telescope to slide back and forth for balancing. A flip-mirror diagonal is supplied. This slides into the 2-inch focuser adaptor ring and presents two ▸

Top performing optics

Without doubt the stand-out feature of the SD103S telescope is its optical performance. Basic refractors suffer from chromatic aberration; this is when short, mid and long wavelengths of visible light appear to reach slightly different focus positions, and cause colour fringing, an effect most visible on the sharp edges of bright objects such as the Moon. The SD103S uses a 103mm diameter doublet lens to reduce this effect. Further improvements occur through the use of FPL-53 glass, a material highly regarded for its low dispersion of different light wavelengths, and which on its own is able to keep chromatic aberration low. The use of this high-performance optical glass is where the 'SD' (Super extra-low Dispersion) comes from in the telescope's name. As a result the SD103S produces stunning, high-contrast views. Diffuse objects such as the Orion and Dumbbell Nebulae are extremely clear, star clusters are vibrant and the shapes of galaxies such as Bode's Galaxy, M81, and the Cigar Galaxy, M82, are easy to make out.

ALL PICTURES: WWW.THESECRETSTUDIO.NET

Lightweight tube

The SD103S's lightweight tube is strong, well built and attractively finished in standard Vixen colours. Inside the tube an improved baffle system increases the amount of light delivered to the edge of large camera sensors compared to previous generation Vixen refractors. A plastic dust cover clips into the end of the non-retractable dew shield.

7x50 finder

A generous 7x50 illuminated finder is supplied. With 7x magnification and 50mm aperture optics, this provides a bright and easy-to-identify section of sky. The finder attaches to the main scope via a three-screw, adjustable mounting. An internal red LED illuminates the finder's cross-hairs to make pointing the scope that bit easier.

Tube rings

The supplied tube rings are clamped and locked onto the telescope body via two thumb screw knobs. Loosening and tightening for tube balance adjustment is easy thanks to the rings being felt lined. A Vixen dovetail plate is provided as standard. A useful carry handle is attached to the top of the rings.

FIRST LIGHT

SKY SAYS...
Now add these:

1. Vixen SD Reducer HD kit

2. Vixen Sphinx SXP2 equatorial Go-To mount

3. Vixen SG-CB90 carbon fibre tripod

▸ T-threads onto which extension tubes and 1.2-inch adaptors are attached. Removing an extension tube allows a T-threaded camera to be connected directly to the diagonal.

The views through the scope were impressive. The Double Cluster in Perseus, NGC 869 and NGC 884, appeared bright and vibrant with good colour definition.

A view of the Orion Nebula, M42, showed lots of detail. The faint outer regions were also beautifully revealed by the scope's high-contrast optics. It was a real pleasure to view this object through the SD103S.

A brighter test view of the Moon showed the apochromatic optics of the SD103S to be true to form, and no colour fringing was seen at any point around the Moon's limb. Using a 5mm Vixen eyepiece (not included) delivered a very comfortable view of the lunar surface with features as small as 10km visible under really quite unsteady conditions.

Similarly, imaging with a camera attached was a pleasurable, stress-free experience. The focuser is responsive and excellent at holding position. It was lovely to image with such a bright, high-contrast field of view. On a less positive note, bright stars exhibit a diffraction pattern, which appears to originate from the clips used to hold the objective in place. In addition, large sensor images do show some optical distortion of stars towards the corners of the imaging frame. An optional matching Vixen reducer/field-flattener goes some way to alleviating the distortions, but in our experience didn't fully eliminate them. Despite this, approximately 85 per cent of the inner frame still produced a great image.

The Vixen SD103S is a strong performer both visually and photographically. Its portability is another factor in its favour too. Consequently, this is a no-fuss instrument that is capable of delivering excellent results. Ⓢ

Verdict

Assembly	★★★★☆
Build and design	★★★★☆
Ease of use	★★★☆☆
Features	★★★★☆
Optics	★★★★☆
OVERALL	★★★★☆

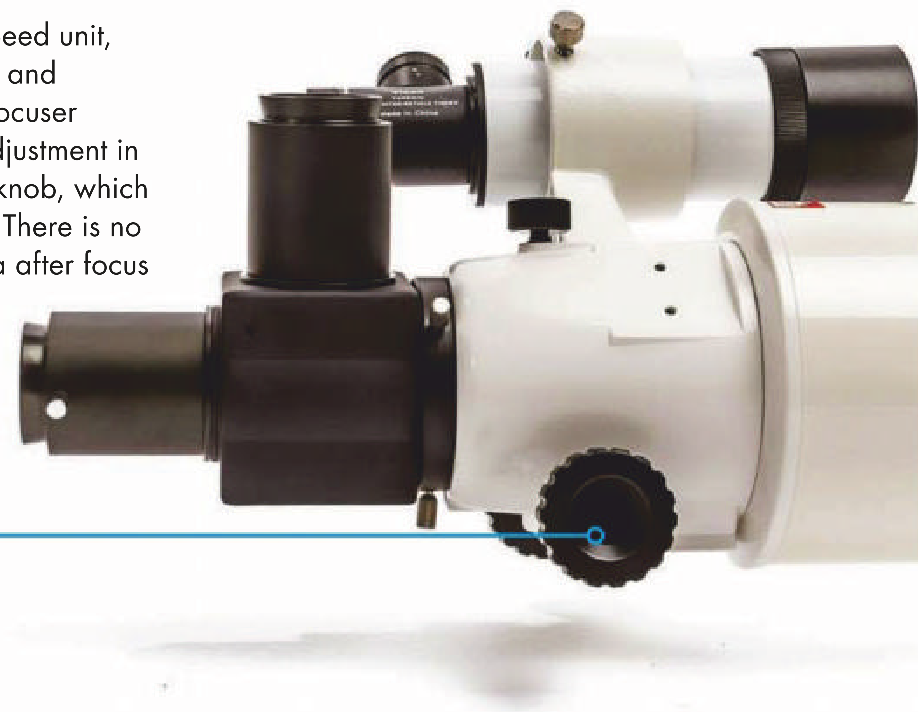
WWW.THESECRETSTUDIO.NET, PETE LAWRENCE

Flip-mirror diagonal

A flip-mirror diagonal unit is provided. This incorporates an internal mirror moved via an external knob. One position puts the mirror out of the way with the focus position aligned along the telescope's optical axis. In the 45° position, the focus point is sent to a second eyepiece barrel at 90° to the scope's optical axis.

Focuser

The focuser is a single-speed unit, which proved responsive and smooth. Apart from the focuser knobs, there's just one adjustment in the form of a tensioning knob, which also locks the drawtube. There is no ability to rotate a camera after focus has been achieved.



A largely unprocessed, 30" single exposure of the Dumbbell Nebula, M27, shows slight vignetting in the corners. Star shapes are good for much of the field of view

See an interactive 360° model of this scope at www.skyatnightmagazine.com/startravel-102

Sky-Watcher Startravel-102 AZ-GTe

WORDS: PAUL MONEY

Get connected – the smart way to control your mount is with a mobile device

VITAL STATS

- **Price** £379
- **Optics** 102mm, two-element, air-spaced achromatic refractor
- **Focal length** 500mm, f/4.9
- **Mount** AZ-GTe Wi-Fi Go-To altaz mount
- **Ports** Power connector, DSLR shutter release port, hand controller connector, Wi-Fi module
- **Control** Free SynScan app for iOS and Android mobile devices
- **SynScan app database** 10,000+ objects including Messier, NGC, IC, Caldwell, Solar System and more
- **Tripod** Adjustable tripod with accessories tray and vertical extension
- **Power** 8xAA batteries or DC 7.5~14V, 0.75A tip positive
- **Extras:** Red dot finder, 25mm and 10mm 1.25-inch fit eyepieces, star diagonal
- **Weight** 6.65kg
- **Supplier** Optical Vision Ltd
- **Tel** 01359 244200
- **Web** www.opticalvision.co.uk

WWW.THESECRETSTUDIO.NET X4, PAUL MONEY X2

We live in an age of smart phones, tablets, Wi-Fi and the 'internet of things', so Sky-Watcher has been quick to integrate Wi-Fi adaptors in its latest mounts, taking advantage of the technology. Here we check out the company's Startravel 102 AZ-GTe system which consists of a 102mm, short-focus refractor and a variant of its AZ-GTi mounts, the AZ-GTe. The Startravel 102 AZ-GTe is supplied with a red dot finder, a star diagonal and two basic but useful eyepieces, 10mm and 25mm. With the 500mm focal length these eyepieces give magnifications of 50x and 20x respectively. An adjustable aluminium tripod with accessory tray and an extension pier complete the system.

It was all very easy to assemble, and we were up and running in no time at all. The AZ-GTe mount differs from the AZ-GTi in that it does not incorporate the Freedom Find dual-axis encoders that allow you to hand-move the mount while retaining Go-To accuracy. In practice, however, if you're careful with the mount then you may not need that feature, and the AZ-GTe works perfectly well as a Go-To mount on its own merits. Power is supplied either by a set of eight AA batteries (not supplied) housed in the side of the mount or via an optional power supply providing DC 7.5~14V, 0.75A tip positive.

SKY SAYS... An innovative system boasting more than just a Wi-Fi gimmick

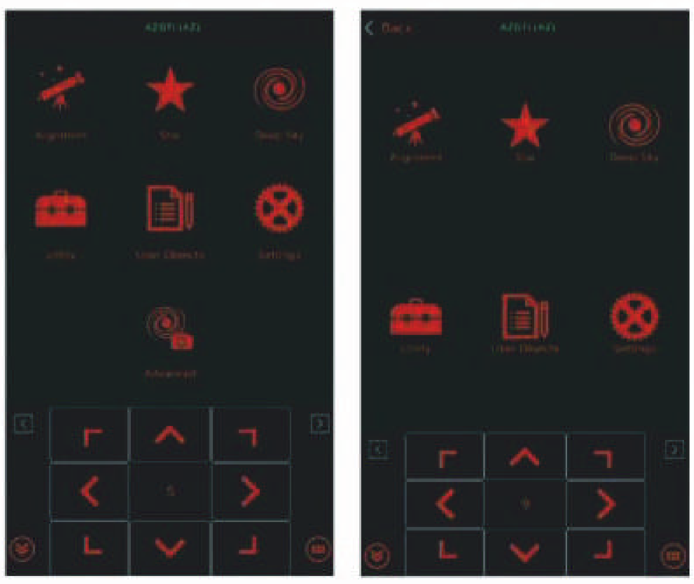
On the optics side, the Startravel 102 is a nice, short-focus refractor with a 102mm, two-element, air-spaced objective with a focal length of 500mm. This makes it a 'fast' system with a focal ratio of f/4.9, which helps with large wide-field views suitable for targets such as the Andromeda Galaxy and the Pleiades star cluster. It is an achromat and works very well for visual use – its primary purpose – although it does display some chromatic aberration (where not all wavelengths come to the same focus) when used for imaging. However, in visual use we didn't notice anything that detracted from using the telescope; Deneb, for example, was pin sharp across almost three quarters of the view in the 25mm eyepiece.

Making a connection

Levelling the tripod and powering up the mount we ensured the tube was pointing north and level. Once ►

Wi-Fi and SynScan

Startravel 102 AZ-GTe is a great way to explore the heavens using a smartphone or tablet. A red LED light flashes when a mobile device connects to the on-board Wi-Fi adaptor. Download the free SynScan app for iOS or Android to control the system from your device via a simple user interface. The app has up to 10,000 objects in its database covering a wide range of the most popular targets. Alignment is easy and there's an option to align with each object once located in the eyepiece, which helps with greater accuracy for targets nearby. Android users can also connect with the SkySafari Planetarium app but Apple users should note that two devices are needed, the first running the SynScan app, the second running SkySafari; once done, though, we found it worked fine.



▲ SynScan's easy-to-use interface for mobile devices

Optics

The Startravel 102 is a two-element, air-spaced, achromatic 4-inch scope with a focal length of 500m. This gives a focal ratio of f/4.9 and so is considered relatively 'fast'. Visually it gives good colour correction with a little chromatic aberration present towards the field edge.

Tripod, accessories tray and extension

The tripod provides good support for the system and has adjustable legs allowing a height range of 80.5cm to 152cm. The extension tube allows the attached telescope to miss the tripod when aiming vertically and the tray helps make the tripod stable and provides somewhere to store eyepieces and accessories.

Focuser and finder

The finder is a zero magnification red dot finder with variable brightness, which worked fine for the task at hand. The focuser is basic but quite sturdy with a smooth motion. The supplied adaptor allows standard 1.25-inch eyepieces to be used via the supplied 1.25-inch star diagonal.

Eyepieces

A 1.25-inch star diagonal and two basic but effective 1.25-inch eyepieces are supplied with the Startravel 102, one with 25mm focal length for wide field views and the other 10mm for higher magnification. For this size telescope they are a good match and gave good views of a wide range of objects.

FIRST LIGHT

SKY SAYS…
Now add these:
1. 7Ah or 17Ah powertank
2. 1.25-inch lunar and planetary filter set
3. Red LED torch

▸ powered, the mount produces its own Wi-Fi network, which you can connect to using your mobile device. Having done that, we opened up the SynScan app and clicked to connect; it found the mount every time and used the smart device's GPS to set the time and date.

We found the 'Brightest Star' alignment worked well using two stars enabling us to place our targets close to the centre of the view of the 25mm eyepiece after it had completed. An interesting option enables you to fine tune each target once centred and accept its position, allowing for greater accuracy for other targets nearby. We did this every time we moved to a new target and could always find our chosen objects close to the centre of the view no matter how much we explored the sky.

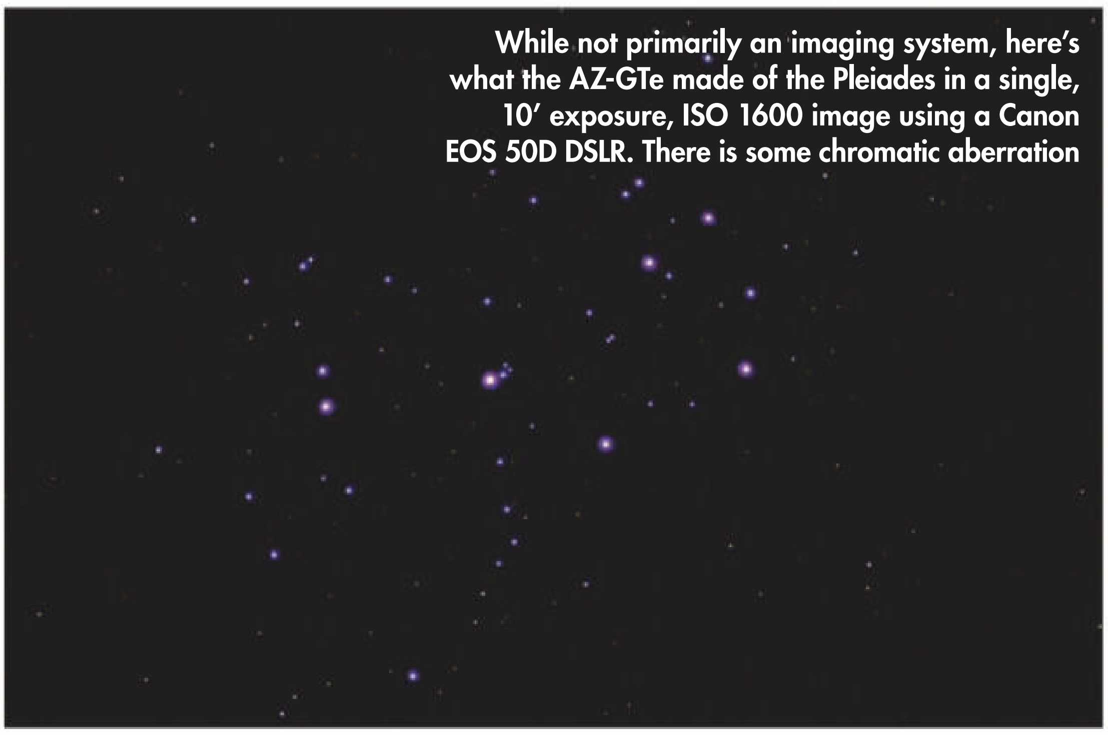
The SynScan database covers the main popular targets most people would choose to view, so we went on a tour taking in M57, the Ring Nebula, Albireo (the stunning gold-blue double star in Cygnus) and M27, the Dumbbell Nebula. It was while observing M37 – a lovely triangular star cluster high overhead – that we discovered the virtues of the tripod's extension tube, which prevented the telescope from catching on the top of the tripod mounting.

We then switched to NGC 7331, a galaxy in Pegasus, detecting a nice 'sliver' of light, although it was quite small. The size is an effect of using a wide- or rich-field scope, but swapping to the 10mm eyepiece helped improve its visibility. The galaxy pair of M81 and M82 looked good in the 10mm whilst the Pleiades sparkled at their best in the 25mm eyepiece. Finally, we took in the Andromeda Galaxy and picked out its two fainter companions for an encore.

Overall it was a pleasure to explore the sky with the Startravel 102 AZ-GTe. If you're not familiar with smart devices there's the option of purchasing a SynScan handset, but for those us comfortable with the connected world, this is a smart new system. Ⓢ

Verdict

Assembly	★★★★★
Build and design	★★★★☆
Ease of use	★★★★☆
Features	★★★★☆
Optics	★★★☆☆
OVERALL	★★★★☆



While not primarily an imaging system, here's what the AZ-GTe made of the Pleiades in a single, 10′ exposure, ISO 1600 image using a Canon EOS 50D DSLR. There is some chromatic aberration

▲ A single-exposure image of the Sword of Orion imaged using the same setup as the Pleiades image above

▲ A single, 1/60″ exposure image of the waning Moon, shot using a Canon EOS 50D DSLR at ISO 100

AZ-GTe motorised base

The AZ-GTe base contains the electronics and gears for altaz operation with a battery compartment for eight AA batteries, a 12V power socket, 'snap' camera plug and an on/off switch. The clutch enables altitude adjustment and tensioning, while on the opposite side the scope is attached with a Vixen-style clamp.

WWW.THESECRETSTUDIO.NET, PAUL MONEY X 3

FIRST **LIGHT**

See an interactive 360° model of these binos at **www.skyatnightmagazine.com/quarkmag**

DayStar Quark Magnesium I b2 solar filter

WORDS: GARY PALMER

An opportunity to look at the Sun in a whole new way yields fascinating results

VITAL STATS

- **Price** £1,199
- **Barrel size** 1.25-inch and 2-inch
- **Tuning range** Wing shifting +/– 0.5Å Wavelength 5172.8Å
- **Power requirement** 5V/2A
- **Extras** Power supply with power lead; protective case
- **Weight** 400g
- **Supplier** Widescreen Centre
- **Tel** 01353 776199
- **www.**widescreen-centre.co.uk

SKY SAYS...
A breakthrough must-have for observing or imaging the Sun

WWW.THESECRETSTUDIO.NET X 5

DayStar has expanded its Quark range of solar eyepieces to include a new wavelength, Magnesium I b2, with some interesting results. Not least of which was that it revealed a entirely new area of interest on the Sun's disc. But more of that later.

The Quark Magnesium I b2 is designed for use with air-spaced refractor telescopes ranging from f/4-f/8. It can be used on telescopes up to 120mm with a UV/IR blocking filter attached. For telescopes above that you will need to contact DayStar about a custom energy rejection filter (ERF) for the front of the telescope as its standard red and yellow ones won't work with the Magnesium Quark.

The filter has its wavelength set at 5172.8Å giving its views a green hue, and so, naturally, it comes in a green case to designate the wavelength of the Sun it explores. Following the design of the original Quark it features a built-in 4.2x telecentric Barlow, a 1.25-inch or 2-inch barrel for mounting it to a telescope and a 1.25-inch fitting on the top so you can attach an eyepiece or camera. A 5V/2A power socket – for heating the filter – and a tuning adjustment knob are both located on the side of the body.

Why the need to heat it up? As DayStar told us, "On all Quarks the heater is to isolate the exact wavelength of the absorption line of the chemical. The accuracy of this tuning needs to be incredibly precise, down to the distance between the nucleus and first electron of a molecule. At this scale, expansion and contraction of the optical components due to temperature changes the target wavelength."

Longer-lasting power

DayStar has made changes to the electronics on this model, reducing the power consumption to allow the unit to run all day on a smaller battery powerpack, a big help if you're using the Quark out in the field or for outreach events.

Setting the Quark up is quite simple. For visual uses it can be inserted in a diagonal with a 1.25-inch eyepiece attached. Turn it on and wait for its ▸

Internal filter

The Magnesium Quark filter is a leap forward in solar observations. In the past very little has been documented using this wavelength and any images that were produced suffered from poor quality because of the equipment used. The I b2-line works well with poor seeing conditions, producing more stable images than other wavelengths, such as calcium, that need very stable conditions to image at high resolution. The resulting structural detail in the images has never been seen before; while Ha images do show some stunning detail, they hide a lot of what's going on between the photosphere and the chromosphere. This filter can see highly magnetised areas close up and, we felt, showed more detail than the calcium and sodium Quarks. Even at a solar minimum the filter excels at finding new areas of interest and study. It's left us looking forward to when the Sun becomes more active.

Power port

The Quark comes with a mains supply with a 1.5A output. This means lots of other power supplies won't work with it and the light will stay orange. For use in the field or away from a mains supply an optional battery pack with a 5V/2A output will run the Quark all day.

LED

A coloured LED shows when the Quark has heated to the correct temperature: it's orange for five to 10 minutes and then goes green when the filter has reached its required temperature and is ready for duty. Red indicates that not enough voltage is reaching the unit or that there is an electrical fault.

Tuning knob

The tuning knob allows you to fine tune the wavelength from a centre value of 5172.8Å by 0.1A with each click, adding or subtracting levels of detail with each adjustment. Each time the knob is adjusted the filter will require around 10 minutes to heat or cool.

Barrel

The Quark has been designed to fit on most refractor-based telescopes and comes with a 2-inch and 1.25-inch barrel. The 2-inch barrel has a cut-out to allow for a more precise 1.25-inch mounting in a diagonal for visual use. Care must be taken inserting it into some shallow 2-inch diagonals as the Quark is quite long and can touch the internal mirror.

FIRST LIGHT

SKY SAYS...
Now add these:
1. Suitable f/4 to f/8 refractor
2. UV/IR blocking filter
3. Energy Rejection Filter – contact DayStar for advice

▸ indicator light to turn green to show that it's ready for use; this takes around 10 minutes in average temperatures.

For imaging it works best on a refractor with no diagonal and will normally require an 80mm extension tube in order to reach focus with a camera.

The Sun is currently close to solar minimum which means that sunspots are small and rare at the moment. The Magnesium Quark shows quite nice detail in and around the sunspots visually, but in our opinion it is better suited to imaging. Details in plage and facula areas are hard to see with the eye as its images are brighter than those produced by the other Quarks.

A new discovery

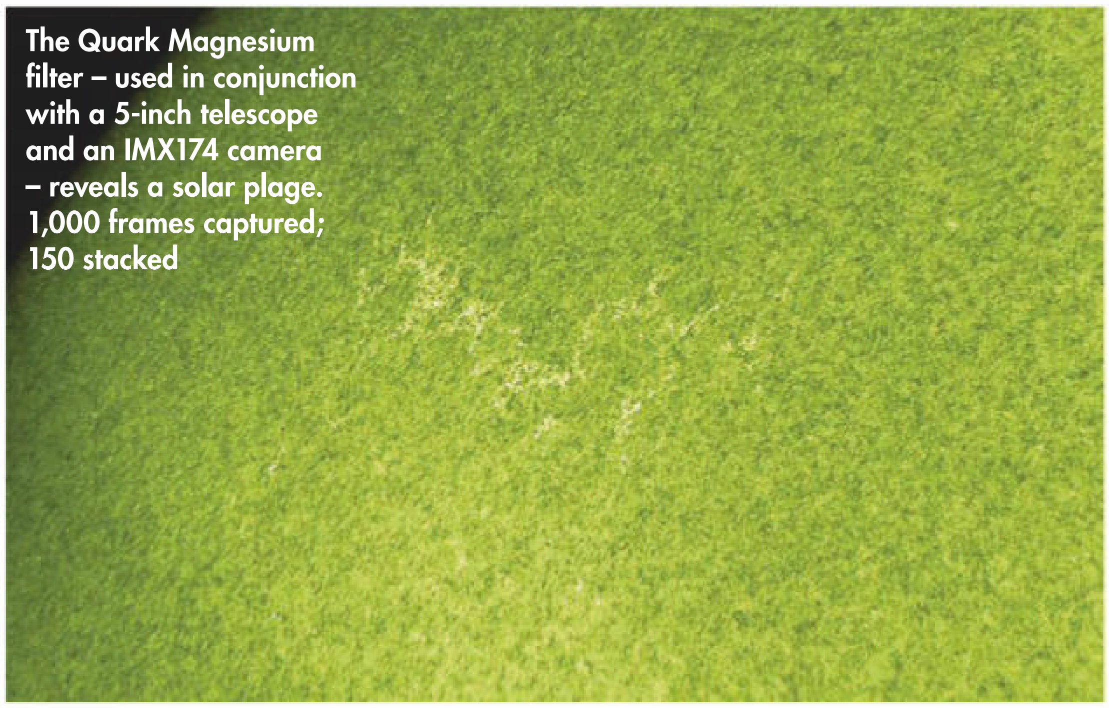
We set up a few imaging tests through the review period and were very impressed with the detail seen on the photosphere of the Sun. The Quark Magnesium seems to reveal a combination of various features seen in other wavelengths. The first noticeable one was the plage areas normally seen in the calcium model. While not as defined as it would be through a CaK filter, it was very clear almost to the limb of the Sun. Looking at other areas we could see granulation that would normally be picked up in the sodium line and the outlines of filaments that resemble the H-alpha and helium views. This was quite surprising and as we played with the tuning knob we could bring out detail in other areas that we've never seen before. Running a side-by-side test with the calcium, sodium and Ha versions of the Quark revealed an area of interest not visible using the other Quarks. What made it even more exiting was that when we checked the image with the manufacturer and others, no one really had an answer as to what the feature was – so, an intriguing observation meriting further study.

All the cameras we tried with the Quark Magnesium I b2 worked very well, though we found the best detail was achieved with a mono camera. Full-disc images can also be achieved using DayStar's Camera Quark adaptor and a Canon or Nikon lens.

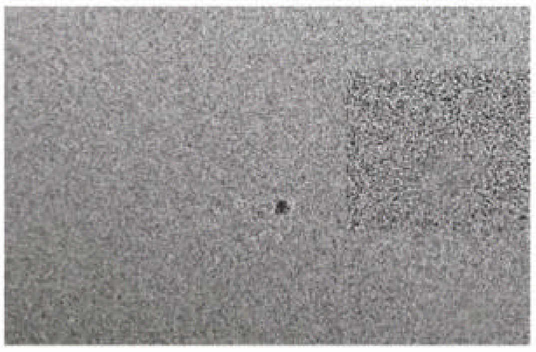
Since its inception, DayStar's Quark range has allowed us to see the Sun in wavelengths once thought of as exotic because of the previously exorbitant price of the kit. The Magnesium I b2, which lets us look into the Sun in a new way again, is a welcome addition to the line-up.

Telecentric Barlow

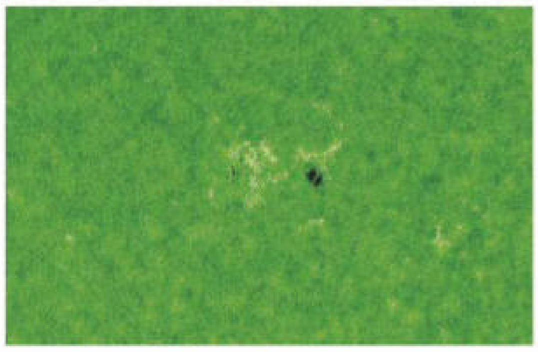
The Quark has been designed for use on f/4 to f/8 refractors. With the built-in 4.2x telecentric Barlow this will result in a long focal length varying with the focal length of the refractor used. This can make objects hard to see or focus on if the Quark is used on equipment with a large aperture.



The Quark Magnesium filter – used in conjunction with a 5-inch telescope and an IMX174 camera – reveals a solar plage. 1,000 frames captured; 150 stacked



▲ An expanded view of the previously unseen area of interest captured using the Quark Magnesium filter



▲ Imaged using the magnesium filter, an IMX290 camera and a 5-inch scope; 1,000 frames captured with 100 stacked

Verdict

Build and design	★★★★★
Ease of use	★★★★★
Features	★★★★★
Imaging quality	★★★★★
Visual quality	★★★☆☆
OVERALL	★★★★☆

WWW.THESECRETSTUDIO.NET, GARY PALMER X 3

Books

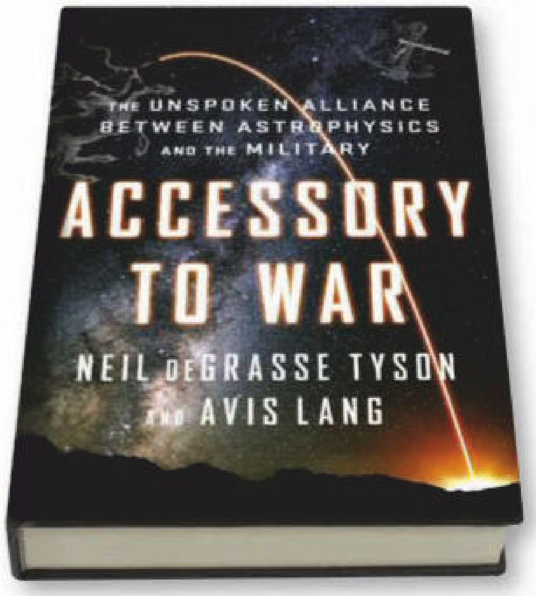
New astronomy and space titles reviewed

RATINGS

★★★★★ Outstanding
★★★★☆ Good
★★★☆☆ Average
★★☆☆☆ Poor
★☆☆☆☆ Avoid

Accessory to War: The Unspoken Alliance Between Astrophysics and the Military

Neil DeGrasse Tyson & Avis Lang
WW Norton
£19.99 • HB



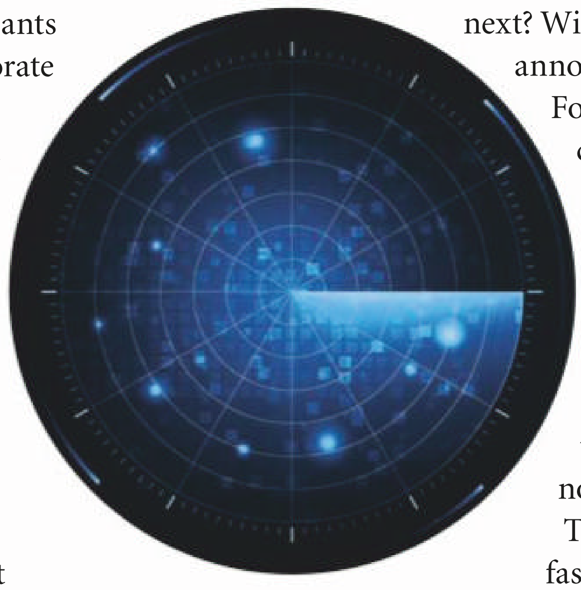
Astrophysicist and *Cosmos* host DeGrasse Tyson explains that this book's inspiration came from attending the National Space Symposium in 2003, where he encountered anti-war protestors who denounced the event as a 'weapons bazaar'. He wrote them off as naïve, until the event displayed live CNN updates of the Iraq invasion, and symposium participants applauded as their corporate military products were name-checked on air. At which point Tyson had to concede that maybe he was the naïve one.

The result is this wide-ranging and very readable history of the overlap between science and the military, penned with editor Avis Lang. History is the right word, because the link goes back a very long way. The idea for radar came from back-of-the-envelope calculations about how much radio energy would be required to boil the blood of enemy aviators. Accurate clocks resulted from an 18th-century challenge by the British Admiralty to better measure longitude so its warships could more reliably navigate the globe. And while Galileo gets the credit for turning the telescope skyward, it was first promoted by 17th-century glass maker Hans Lipperhey as a means of verifying a newly forged peace settlement between Dutch and Spanish forces.

This relationship has only strengthened through recent eras of rocketry, nuclear weapons and killer drones for one compelling reason: it works. Powers possessing greater scientific knowledge tend to win wars. But where does it go next? With the US president announcing a new Space Force, Tyson and Lang consider what war in space might actually mean. With key orbits left unusable by debris, a space war resembles a nuclear war in that it would have no winners, only losers.

The book is a fascinating exploration of humanity's capacity to combine discovery with destruction, but the authors would have us take heart. The single largest artificial object in space remains the explicitly peaceful, low-orbiting International Space Station – and the logic of conflict grows weaker the higher we go.

★★★★☆



Radar in part originated from plans to design a 'death ray'

ISTOCK

SEAN BLAIR *writes for the European Space Agency website*

TWO MINUTES WITH Avis Lang

How far back does the link between astronomy and the military go?
By the end of the first millennium BCE, Chinese court astronomers had chronicled most celestial phenomena visible to the unaided eye. Because there was a presumed relationship between the Universe above and the affairs of state below, these records were treated as classified research, essential to national security.

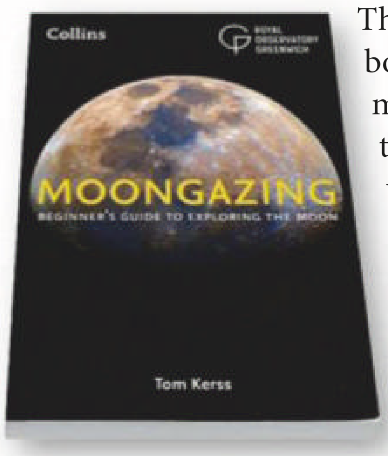
How close did the Cold War come to a full-blown 'space war'?
Although the hyper-aggressive rhetoric in US Cold War documents paints development of the wherewithal for all-out war as a primary goal, the resulting space weaponry didn't fulfil the fantasies. Plus, it soon became clear that physical space war, with its unavoidable yields of dangerous orbiting debris and its damage to essential civilian satellites, could just as easily victimise the weapons' wielder as the weapons' target.

How would you like to see space science and the military collaborate in future?
Ideally, the pursuit of science would be seen as essential to the public good and worthy of non-military public funding. True, on occasion the military has turned to space scientists for help with military problems, help that led to scientific discoveries and advances. But broadly useful, unexpected outcomes do not justify embracing the military as a prime channel for science funding. Its agenda is weighted towards lethality.

AVIS LANG *is a research associate at the American Museum of Natural History's Hayden Planetarium, New York*

Moongazing

Tom Kerss
Collins
£8.99 ● PB



There are many books on the market concerning the Moon, so do we really need another one? Our celestial neighbour is well described in *Moongazing*, albeit briefly. Although the book is only 96 pages long, Tom Kerss, broadcaster and astronomy populariser based at the Royal Observatory Greenwich, manages to cover a broad range of nitty-gritty lunar facts, ranging from the phases to the Apollo missions, and combine it with a detailed practical section on lunar photography using a smartphone or DSLR affixed to a telescope.

The most exciting and informative segment is the 32-page 'Introduction to the Lunar Atlas'. Kerss has divided the Moon into 16 sections and included lunar photographs for each of those sections, along with a map for readers to learn the names of the various craters and various maria. There is an informative two-page segment on surface features and the categories they fall into, which ties in nicely with the maps and provides enough information to identify the features on the Moon's surface.

Moongazing doesn't cover any original topics per se, and there are many books out there covering similar ground, but it is a great reference guide for the beginner or amateur moonthusiast. The small size and weight of the book means it can be easily popped into a bag for a night's lunar observing, and beginners will find the feature-observing log template beneficial.

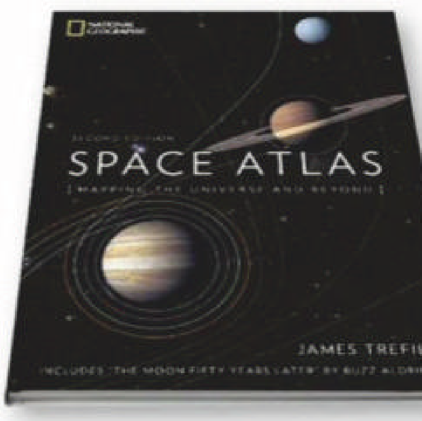
So the answer is yes: we always need new books on the Moon! Whether observing using binoculars or a telescope, there is much to learn from this instructive and inspiring book, which will appeal to Moon fans everywhere.

★★★★☆

KATRIN RAYNOR-EVANS *is an amateur astronomer, a Fellow of the Royal Astronomical Society and the librarian for Cardiff Astronomical Society*

Space Atlas:
Mapping the Universe and Beyond

James Trefil
National Geographic
£30 ● HB



Winds on Venus blow 60 times as fast as the surface rotates. Jupiter's moon Io has more than 400 active volcanoes. The most massive galaxy we know of (M87) is six trillion solar masses. And our Universe may be shedding little baby universes as you read this.

The second edition of the acclaimed *Space Atlas* is chock full of facts about every aspect of our Solar System and beyond. Everything you ever wanted to know about pretty much anything in the Universe is here.

The chapters are beautifully laid out and clearly written with full details, completely updated for this new edition, about the formation, evolution, composition and properties of more celestial bodies than you could shake a telescope at. There is comprehensive information on space missions and scientists, the latest research, cosmology and theoretical physics. Added to that are intricate maps of every planet, the major moons, dwarf planets and larger asteroids, complete with map references so you can easily locate any feature.

This second edition has a wonderful foreword by Apollo astronaut and all-round space hero Buzz Aldrin, which celebrates 50 years since he landed on the Moon and looks ahead to our colonisation of Mars. But all of this is nothing compared to the jaw-dropping images that pack this book. *Space Atlas* is for anyone, expert or complete beginner, who likes their information served up with an extra-large helping of eye candy.

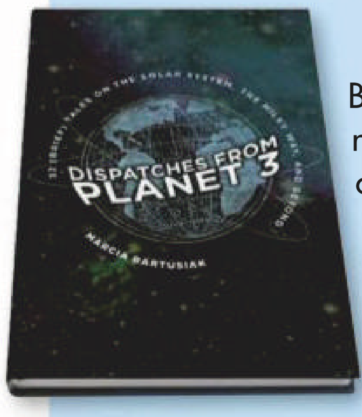
★★★★★

JENNY WINDER *is a science writer, astronomer and broadcaster*

Dispatches from Planet 3

Marcia Bartusiak
Yale University Press
£18.99 ● HB

BOOK OF THE MONTH



Bartusiak's new book craftily combines lucid and accessible descriptions of science with the personal stories of the people who have unlocked the finer details of the Universe.

With liberal use of anecdotes and quotations, Bartusiak covers the normal – comets, planets, white dwarfs, neutron stars, pulsars, galaxies – as well as the oddities of the Universe – quasars, black holes, the Big Bang, dark matter, etc. Bartusiak leads us expertly through the physics: spectroscopy, atomic theory, quantum theory, stellar nucleosynthesis, galactic and extragalactic dynamics, general relativity and cosmological models. At each juncture, she ably explains how diverse fields of research often unify in reaching staggering conclusions.

This is essentially a collection of vignettes, some previously published as articles in popular magazines. Although there is some repetition, it means that each succinct chapter can be read in isolation – a significant plus, as you can dip into the subject matter when and how you please. There is some welcome emphasis on female astronomers, from Henrietta Swan Leavitt and Cecilia Payne-Gaposchkin to Margaret Burbidge and Jocelyn Bell Burnell.

This is a fascinating read, but also serves as a contemporary history of some of the most momentous insights of modern science. An excellent book to see us through those cloudy nights this winter!

★★★★★

DR ALASTAIR GUNN *is a radio astronomer at Jodrell Bank Observatory in Cheshire*

Gear

Elizabeth Pearson rounds up the latest astronomical accessories

1


2


3


1 Nirvana-ES 7mm 82° wide-angle eyepiece

Price £75 • **Supplier** Harrison Telescopes
www.harrisontelescopes.co.uk

This ultra wide-angle, 1.25-inch eyepiece offers a huge 82° field of view for a wonderfully immersive viewing experience.

2 Farpoint DSLR Bahtinov focusing mask

Price £12.80 • **Supplier** 365 Astronomy
020 3384 5187 • www.365astronomy.com

Take the pain out of focusing your DSLR for astrophotography by snapping one of these directly onto your lens. Available in 62mm, 67mm, 72mm, 77mm and 82mm sizes.

3 Vans x Space Voyager shoes

Price £110 • **Supplier** Vans
0800 234 6152 • www.vans.co.uk

Inspired by the Apollo space suits, these Vans shoes come with reinforced toecaps and are adorned with an Apollo 11 mission patch.

4 Omegon Pro Tritron binoviewer

Price £329 • **Supplier** Astroshop.eu
020 3868 8042 • www.astroshop.eu

This binoviewer allows you to look through your telescope with both eyes for a more comfortable viewing experience.

5 Geoptik 5kg counterweight

Price €63.94 • **Supplier** Geoptik
+39 045 925 0989 • www.geoptik.com

Balance your scope to keep it on target with the help of this 5kg counterweight. Internal diameter is 40mm, though adaptors are available for thinner counterweight bars.

6 Solar System bracelet

Price £10 • **Supplier** AstroCymru
www.astrocymrushop.co.uk

Keep the planets close to hand with this bracelet of the Solar System. Features the eight planets, the Sun, asteroid belt and comets, separated by scale distances.

4


5


6


WHAT I REALLY WANT TO KNOW IS...
What secrets will Ultima Thule reveal?

New Horizons' principal investigator **Dr Alan Stern** awaits an encounter with the furthest object from Earth ever studied

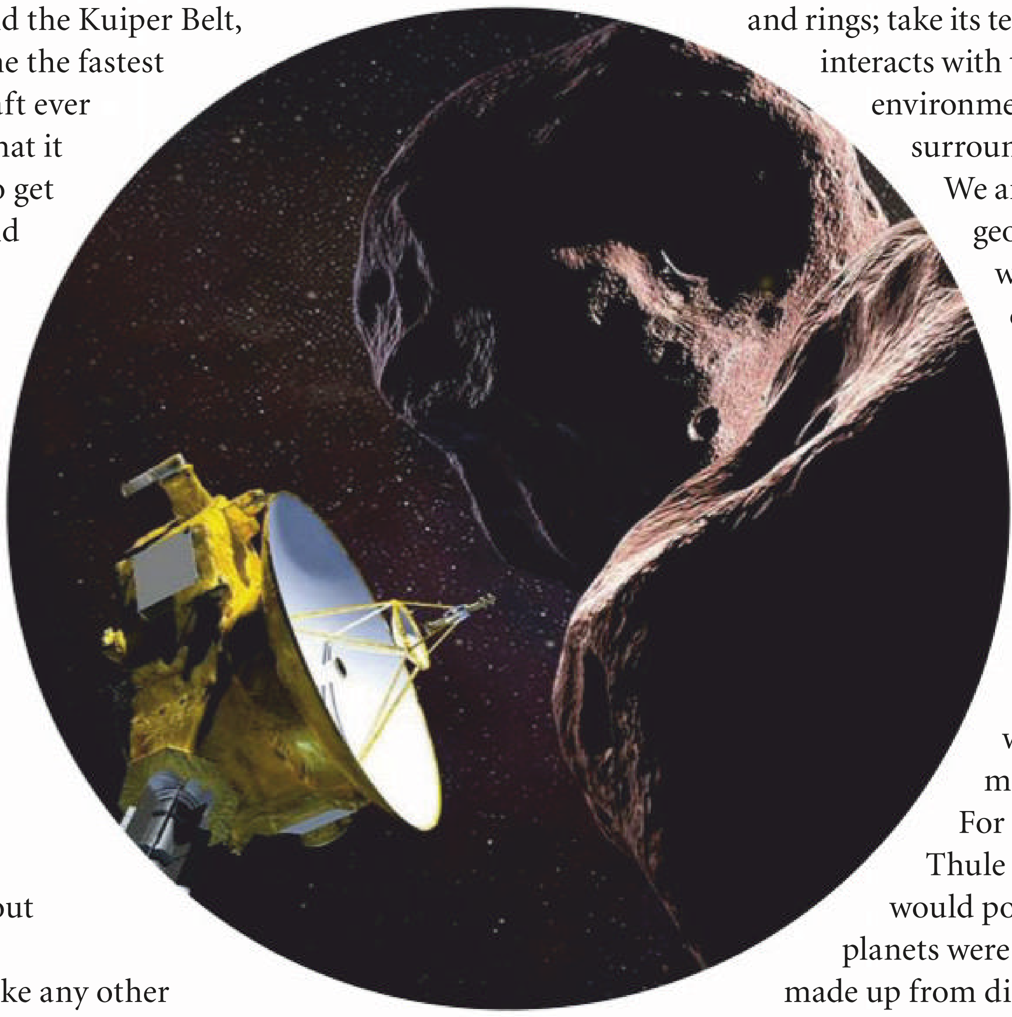
INTERVIEWED BY SHAONI BHATTACHARYA

When New Horizons launched in January 2006, with a specific mission to explore Pluto and the Kuiper Belt, it became the fastest spacecraft ever launched. So, when I tell you that it took us nine and a half years to get to Pluto, then another three and a half to Ultima Thule, it's not because we were dawdling.

We are travelling over one million kilometres a day which is the distance from Earth to the Moon and back again, and then some. New Horizons reached Pluto in July 2015, and that autumn we fired our engines to redirect our course to Ultima Thule (pronounced 'ultima too-leh'). We are just about to intercept this unique world on 1 January 2019. It is six billion kilometres from Earth and about 30km in diameter.

Ultima Thule is a world unlike any other that has been explored by spacecraft. It is located in the third zone of our Solar System – in the realm beyond the giant planets called the Kuiper Belt – and it's about the size of London. We know very little about it except that it formed at the birth of our Solar System, four and a half billion years ago.

It has never left the Kuiper Belt, meaning that Ultima Thule has always existed at a temperature near absolute zero. It's scientifically valuable because it's a frozen relic of the ancient Solar System and we have never had a chance to study something so well preserved from that early era. It will tell us about how planets like Pluto formed.



On New Year's Day 2019, New Horizons will make a flyby of the Kuiper Belt object Ultima Thule, which has, in effect, been frozen in time since the very earliest days of the Solar System

NASA/JHUAPL/SWRI

Checking the coast is clear

Before we get to Ultima Thule we will be using the onboard telescopes and cameras to search for hazards, because the spaceship is travelling so fast (50,000km/h) that even striking something the size of a rice pellet could be fatal.

We will use our cameras to navigate to the target, making course corrections based upon their imagery and we will transmit (by radio) the flyby instructions. During the flyby we will be using all seven science instruments aboard New Horizons to collect valuable data. We will map Ultima Thule; search for moons and rings; take its temperature; determine how it interacts with the solar wind and the local environment; and see whether it's surrounded by any dust (icy grains).

We are going to find out about its geology and composition, and whether it is orbited by anything or has an atmosphere.

We will study Ultima Thule at a higher resolution than Pluto. Our closest approach to Pluto was about 13,000km. At Ultima, we will travel within 3,500km – almost four times closer than we got to Pluto.

Hopefully, these findings will help us decide between models of planetary formation. For example, if we find that Ultima Thule is a monolithic structure that would point towards one theory of how planets were formed. Or we may find it is made up from different compositions which would indicate another theory.

Reporting back

We've decided that the spacecraft will spend its time making science observations and not communicating with Earth. We are only close to Ultima Thule for less than a day and New Horizons won't report back until about four hours after the closest approach. The signal takes about six hours to reach us and that first report will have no imagery or science data. Then it will begin to download imagery and, each day for four days, send home better and better data.

It will take about 20 months to transmit this all back. During this time, in addition to analysing the results, our team will start searching for another target to propose to NASA. As New Horizons has the fuel to operate into the mid 2030s, a visit to another Kuiper Belt object is very likely before 2027.

Looking ahead to Ultima Thule, it's a very challenging mission. No spacecraft in history has ever conducted a flyby of a world so far away, so we are breaking all the records. The team is feeling excited and we are raring to go. Ⓢ

ABOUT DR ALAN STERN

Dr Alan Stern is a planetary scientist, space program executive, aerospace consultant and author. He leads NASA's New Horizons mission to Pluto and the Kuiper Belt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127mm Essential Version £1330
102mm FCD100 Deluxe - £1330
102mm Essential Version- £847
80m Deluxe FCD100 Apo - £891
80mm Essential Apo £562
Explore Scientific Sun Catcher Solar Filters From £18
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82° Degree Explore Scientific eyepieces from £124
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THE SOUTHERN HEMISPHERE IN JANUARY

With Glenn Dawes

WHEN TO USE THIS CHART

1 JAN AT 24:00 AEDT (13.00 UT)
15 JAN AT 24:00 AEDT (13.00 UT)
31 JAN AT 23:00 AEDT (12.00 UT)

The chart accurately matches the sky on the dates and times shown for Sydney, Australia. The sky is different at other times as the stars crossing it set four minutes earlier each night.

JANUARY HIGHLIGHTS

The sight of the two brightest planets, Venus and Jupiter, close together can be spectacular. Their closest conjunctions occur when they pass each other, which happens at least yearly, but two such close passes are due to happen in 2019. The first is on 23 January when they're separated by just 2.3°. Then later in the year on 24 November, Venus will pass Jupiter at a distance of only 1.4° as Venus rises in the west and Jupiter drops towards its December conjunction.

STARS AND CONSTELLATIONS

Canis Major might be best known for Sirius, the brightest star in the heavens, but its hindquarters are formed by a remarkable group known as 'the Virgins'. Arranged in a distorted Mercedes Benz logo shape, Epsilon (ε), Eta (η), Omicron² (o²) and Delta (δ) Canis Majoris (mag. +1.5, +2.4, +3.0 and +1.8 respectively) are four of the most luminous stars known. Omicron²'s faintness is only due to its sheer distance of 3,400 lightyears. The star's brilliance is actually over 60,000 times that of our Sun!

THE PLANETS

January evenings are slim pickings with Mars the only naked-eye planet visible, setting about 23:00 AEDT. Mornings see Venus low in the east, around an hour before dawn. As mentioned above, Jupiter is not far from Venus, rising around 02:00 AEDT midmonth. Mercury concludes a poor morning return, becoming too low to observe and in the Sun's glare by midmonth. As this speedy messenger departs, Saturn races past, returning to the morning, rising at 03:00 AEDT by month's end.

DEEP-SKY OBJECTS

The constellation of Dorado is famous for the Large Magellanic Cloud but is also home to some other more distant galaxies. Find mag. +3.27 Alpha (α) Doradus, and 0.5° northwest lies the mag. +10.3, edge-on spiral galaxy NGC 1617 (RA 4hr 31.7m, Dec. –54° 36') which has a stellar nucleus with an intense elongated core of about 4x1 arcminutes.

From there, move 4.5° south-southeast to the barred spiral NGC 1672 (pictured: RA 4hr 45.7m, Dec. –59° 15'). The mag. +9.7 galaxy is an extended nebulous object that offers much to the patient observer. It has a small, round nucleus with a hazy oval core extending east-west (its bar). A fainter halo extends northward. Averted vision shows mottling and, if you're lucky, the ghostly image of its only spiral arm extending from the eastern end of the bar to the north.

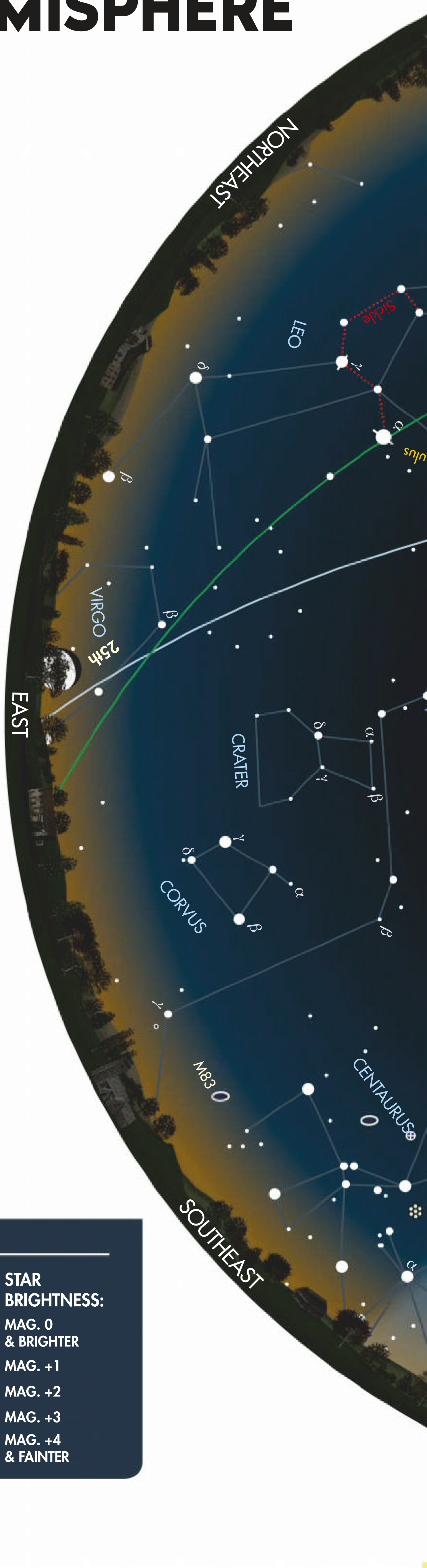
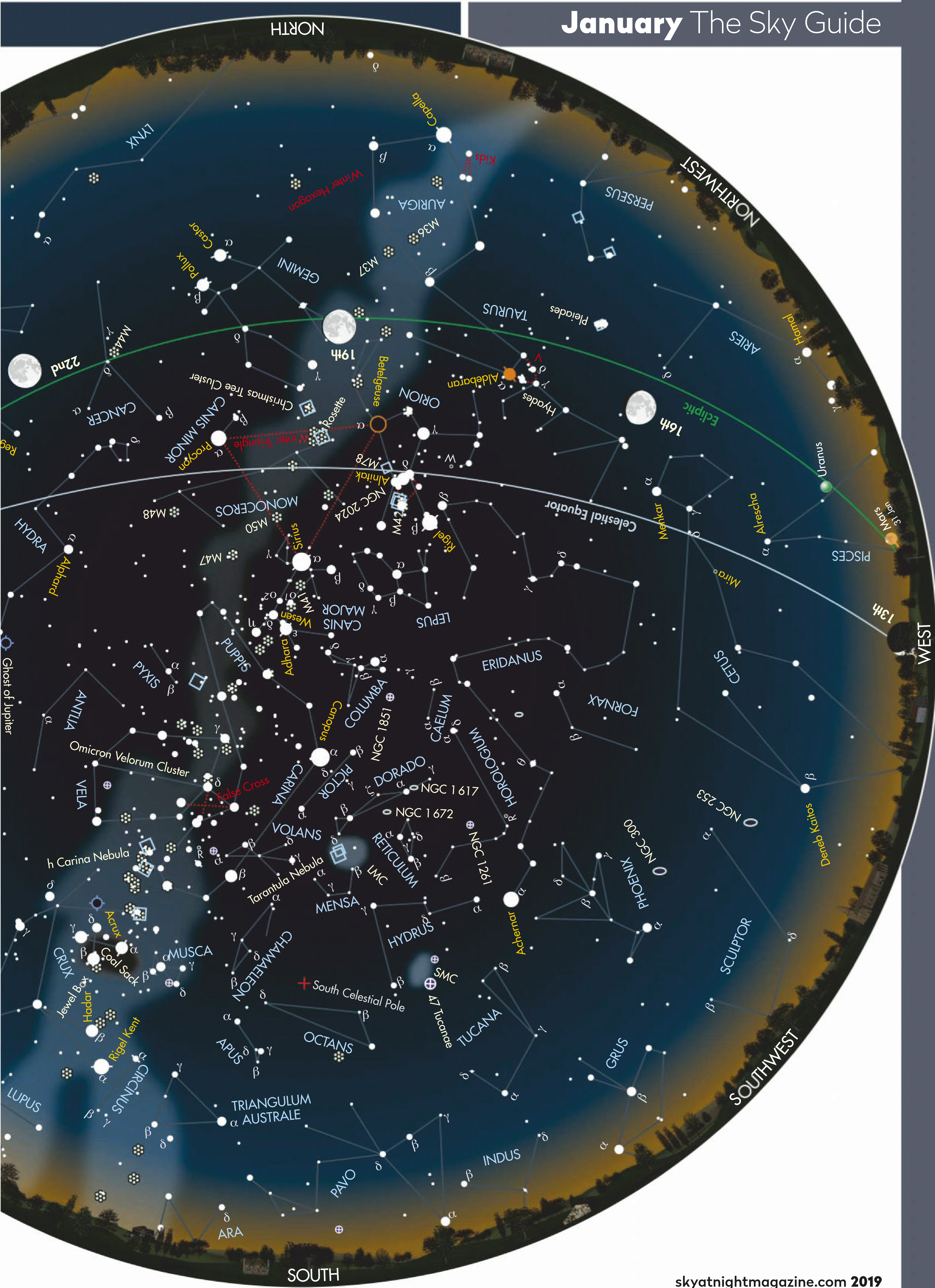


CHART KEY

- GALAXY
- OPEN CLUSTER
- GLOBULAR CLUSTER
- PLANETARY NEBULA
- DIFFUSE NEBULOSITY
- DOUBLE STAR
- VARIABLE STAR
- COMET TRACK
- ASTEROID TRACK
- METEOR RADIANT
- QUASAR
- PLANET

STAR BRIGHTNESS:
- MAG. 0 & BRIGHTER
- MAG. +1
- MAG. +2
- MAG. +3
- MAG. +4 & FAINTER


NORTH
NORTHWEST
WEST
SOUTHWEST
SOUTH
LYNX
Capella
Kids
AURIGA
Winter Hexagon
PERSEUS
M36
M37
Castor
Pollux
GEMINI
TAURUS
Pleiades
22nd
19th
16th
M44
CANCER
Christmas Tree Cluster
CANIS MINOR
Procyon
Winter Triangle
Rosette
Betelgeuse
ORION
Aldebaran
Hyades
Ecliptic
ARIES
Hamal
Uranus
Mars
31 Jan
Alrescha
PISCES
Menkar
Celestial Equator
M78
Alnitak
NGC 2024
M42
Rigel
MONOCEROS
M48
M50
HYDRA
Alphard
Sirius
M47
M41
CANIS MAJOR
Wesen
LEPUS
Mira
13th
CETUS
Ghost of Jupiter
PUPPIS
Adhara
PYXIS
ERIDANUS
FORNAX
ANTLIA
COLUMBA
NGC 1851
Canopus
CAELUM
HOROLOGIUM
Omicron Velorum Cluster
VELA
CARINA
False Cross
PICTOR
DORADO
NGC 1617
NGC 1672
NGC 253
NGC 300
Deneb Kaitos
h Carina Nebula
VOLANS
Tarantula Nebula
LMC
RETICULUM
NGC 1261
PHOENIX
MENSA
Acrux
CRUX
Coal Sack
MUSCA
HYDRUS
Achernar
SCULPTOR
CHAMAELEON
SMC
Jewel Box
Hadar
South Celestial Pole
47 Tucanae
TUCANA
Rigel Kent
APUS
OCTANS
GRUS
CIRCINUS
LUPUS
TRIANGULUM AUSTRALE
PAVO
INDUS
ARA